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# AGRICULTURAL GEOLOGY

BY

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# PREFACE

Because of the death of my husband, it is not possible to acknowledge all the helpful suggestions and criticisms offered by his various scientific friends, but I recall that he considered the suggestions of Doctor Heinrich Ries, of Cornell University, as very valuable, and that Professor L. E. Call, of Kansas State Agricultural College, and Professor A. F. Kidder, of Louisiana State University, both read several chapters and made helpful suggestions and criticisms. There were, however, other friends, whose names I do not know, who rendered similar services.

H. L. Emerson.

East Providence, R. I,, April, 1920.

## NOTE TO SECOND PRINTING

In the second printing of this book, Doctor Heinrich Ries has kindly helped in the revisions and has entirely rewritten the subject matter on the general origin of phosphate deposits. Professor Arthur M. Miller of the University of Kentucky has contributed three paragraphs on soil inheritance as illustrated from the Bluegrass region of Kentucky and has also helped in correcting typographical and other errors.

H. L. Emerson.

East Providence, R. I., February, 1922.

# FOREWORD

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Geology and Agriculture are closely related, indeed it is due to geological processes that the hard rocks are broken down to soil, and essential mineral substances set free which in some cases affect the physical qualities of the derived soil, and in others serve as sources of plant food.

It therefore follows that the student of agriculture should have at least an elementary knowledge of the processes and principles of Geology, with especial reference to the geology of soils and fertilizers.

With this object in view the late Professor Emerson prepared the accompanying work, but unfortunately his untimely death prevented his seeing it through the press, the labor of this devolving on Mrs. Emerson.

The subject matter and mode of treatment are the outgrowth of some years of experience in teaching geology to agricultural students, and while Professor Emerson prepared the work primarily for class-room use, it was also his hope that it might prove serviceable for reading and correspondence classes.

On this account he endeavored to make the treatment as untechnical as possible, without sacrificing scientific accuracy.

Those who desire to follow the subject in greater detail can do so with the aid of the appended bibliographies and lists of soil and geological maps. Professor Emerson also gave considerable attention to the selection of illustrations, choosing them with the purpose of showing specific items on phenomena.

H. Ries.

Ithaca, N. Y., April, 1920.

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# AGRICULTURAL GEOLOGY

## INTRODUCTION

Geology as a whole is essentially the study of the earth's history. All the different lines of geological investigation contribute directly or indirectly to this end and the study of present-day processes helps to explain what has occurred in the past. To take an example, Fig. 1

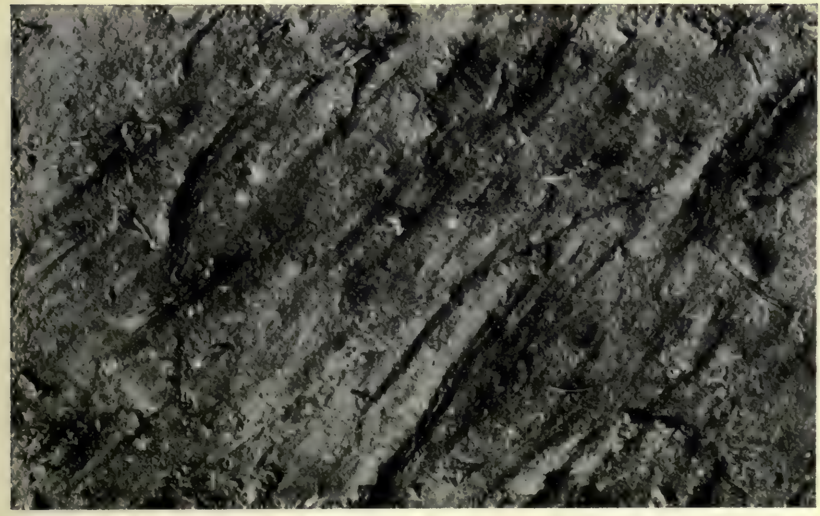

Fig. 1.—A rock record of an ancient beach. Note the long rill marks made by running water and the round spots (rain prints) made by falling rain drops.

shows the rain pits and rill marks as contained in old sandstone which has preserved the evidences of beach conditions almost as perfectly as may be found after a storm on a modern beach. By these fossil rain prints and stream marks we know that this rock was accumulated near an ancient beach. The study of present peat beds leads to an understanding of how the ancient coal beds were formed. The traces of modern glaciers are similar to those of very ancient glaciers. Many other instances might be cited to show how the observation of present geological conditions enables us to work out past geological history.

**Divisions.**—As in other sciences different phases of geology may be considered or emphasized for special purposes. Thus *historical geology* treats primarily of the succession of events as determined by the study of rocks and their remains of plants and animals (fossils). *Dynamical Geology* has to do with the forces which have changed and are now changing the earth. *Physiographic geology* or *physiography* deals with processes which are now modifying the earth's surface. *Structural geology* is the study of the materials of the earth and how they are arranged. *Economic geology* deals with whatever geological factors may have commercial interest. *Agricultural geology*, with which this volume is concerned, deals mainly with soils, and to a less extent, with the origin of mineral fertilizers.

## Fundamental Ideas

One of the first ideas to be acquired in the study of geology is the vast length of time involved. The accumulation of an inch of limestone soils has required a vastly longer period than the length of known historical time, and a realization of this should lead to a conservation of our soils, which have required so long a time for their formation and will require an equally long time for their replacement. Even a moderately high hill has usually been tens of thousands of years in the making and, if a mountain range had been started when the Pilgrims landed at Plymouth in 1620, it is entirely probable that this would not be known to-day, so slow is the process of mountain making.

Although the study of soil origin is but one of the many viewpoints of geology, yet there is no agent or process of geology which is not in some way directly related to soils. Obviously when rocks weather or break up they form vast areas of residual soils so that we speak of granite soils, limestone soils and so forth, each rock usually contributing a distinctive soil. But even the soil from a rock like granite will vary under different conditions, for a granite soil in a dry country differs notably from one in a humid region and one in a hilly country has different features from one in a level region. Then soils from different rocks are usually different in composition; granite soils often have a somewhat high potash content and sandstone soils usually have a low content of mineral plant foods and, moreover, soils from different rocks often differ both in their soil minerals and in chemical composition so that the composition of the parent rocks must be considered.

About the most stable thing that we know is the earth's surface, yet geology teaches that the oceans and the lands of North America and elsewhere have many times changed places and, indeed, are doing so to-day. As a consequence of these movements there have been upward movements that have brought large areas of rocks and soils, like the Coastal Plain of North America, above the ocean while downward movements have submerged thousands of square miles of former soils.

Among the most important soils are those that have been transported and deposited so that some soils show but little relation to the underlying rocks. A heavy clay soil, for example, may have been deposited over sandstone, thus giving a soil much unlike the sandy soil which might be expected from a sandstone. Probably the most widespread transporting agent is the winds which, as we shall see, have carried and are now carrying vast amounts of soil-forming materials. Then, in the past, vast glaciers overrode more than half of North America and considerable areas in Europe. These glaciers had most notable effects on soils so that glacial soils are usually distinctive, for not only are glacial soil materials more or less mixtures of various materials that have been transported, but glaciers further modified the drainage and topography, both very important soil and agricultural features. Perhaps the most familiar transported soils are those laid down by running water, for except in very dry regions, there are many streams and all carry some sediment which they deposit at various places. There are large areas of alluvial soils like those of the Mississippi, but even in hilly regions with narrow valleys, these " bottom soils " are important in value if not in area.

But the geological story of soils is not concluded when we have considered their origin, for soils are affected not only by their origin and materials but also by the agents which have modified them since the soils were formed. Among these are the ground and soil water, which here may leach the soils of their soluble minerals and there may deposit materials in the soils. Furthermore the movements of ground and soil waters have an obvious relation to soil moisture and to wells and springs. Then, of course, soils, like rocks, are affected by weathering, that is by temperature changes, freezing and thawing and other agents. For example, soils from the same kind of rock in North Carolina and New Jersey differ because of the difference in the agents and processes to which the soils have been subjected since their formation. Thus it is seen that all the geological agents and processes combine in different ways to affect the soils.

In this study the rocks will first be considered since they are the ultimate source of nearly all soils. We shall also note the different processes by which soil materials are transported from place to place and in general how soils are affected by geological processes.

## CHAPTER I

## MINERALS [1]

An observer by the lower Mississippi where the river has deposited fine soils may see no connection between his soil and a rock, say, like granite. But if he examines the very fine materials of soil through a microscope he is likely to find minerals which came originally from granite-like rocks. Hence it is that we begin the geological study of soils with a consideration of rocks because practically all soils except muck must at one time or another have been a part of some rock. Furthermore, since rocks are usually composed of two or more minerals, the study of minerals will be taken up first, in order the better to understand the materials of which rocks are made.

Fortunately for simplicity of study, the common and important minerals are relatively few, although hundreds have been identified. Likewise the mineral composition of the earth's crust is comparatively simple. According to Clark's estimate the relative percentages in the earth's crust are as follows: [2]

| | | | |
|---|---|---|---|
| Oxygen | 47.33 | Titanium | .46 |
| Silicon | 27.74 | Carbon | .19 |
| Aluminum | 7.85 | Phosphorus | .12 |
| Iron | 4.50 | Manganese | .08 |
| Calcium | 3.47 | Sulphur | .12 |
| Magnesium | 2.24 | Barium | .08 |
| Sodium | 2.46 | Strontium | .02 |
| Potassium | 2.46 | Chlorine | .06 |
| Fluorine | .10 | | |

It will be seen that the elements oxygen and silicon comprise 75 per cent and these with eighteen other elements comprise nearly 99 per cent of the rocks so far as they have been studied. Many important

[1] It is hardly necessary to state that the student must study actual specimens in order to gain a knowledge of minerals.

[2] The Data of Geochemistry, Bulletin No. 619, U. S. Geological Survey, 1916, page 34.

elements, such as lead and copper, show a very small fraction of 1 per cent and do not appear in the above table.

These elements are nearly always combined. Silicon and oxygen unite to form the familiar mineral quartz ($SiO_2$) composed of one part of silicon and two parts of oxygen. Pure iron, for example, is very rare although it is very common in compounds the world over. The number of important minerals is comparatively small since scarcely more than a dozen of great groups include most of the minerals to be found in average rocks. Thus the student may hope by comparatively brief study to recognize most of the minerals which he is likely to find.

## General Characters of Minerals

**Color** is a quality which is easily noted but with many minerals the color is variable. Pyrite, " fools' gold," is brassy yellow, while calcite, the common lime mineral, may have many colors although it is usually white.

**Luster** is due to reflection of light from surfaces of minerals. Luster may be *glassy* like fractured glass; *resinous* as in sphalerite; *pearly* as in mother-of-pearl; *silky* as with fibrous minerals like satin spar and *dull* as in kaolin. Many minerals, as for example, pyrite, have *metallic* luster.

**Streak** is the color of powdered mineral and with fairly soft minerals it may be obtained by rubbing the mineral on a surface like that of unglazed porcelain. Harder minerals may be pulverized. Streak sometimes varies from color, and being fairly constant is a useful characteristic.

**Hardness** of fresh minerals refers to the ease with which they are scratched. Hardness is often stated in terms of Mohr's scale as follows, the type minerals being in order of hardness from soft to hard:

1. Talc
2. Crystallized gypsum
3. Calcite
4. Fluorite
5. Apatite
6. Orthoclase
7. Quartz
8. Topaz
9. Corundum
10. Diamond

For field determinations and for most purposes the following scale will be sufficient:

Very soft, No. 1, easi'y scratched by finger nail.

Soft, No. 2, just scratched by finger nail.

Hard, No. 3, scratched by a copper coin; not scratched by finger nail.

Hard, No. 4, not scratched by copper coin but easily scratched by a knife.

Hard, No. 5, just scratches glass.

Very hard, No. 6, scratches glass easily.

From 7 to 10 the hardness is difficult to determine and requires considerable training for its determination, but with a set of standard minerals, one can become used to the " feel " of hardness.

**Tenacity.**—A mineral is *brittle* when easily broken to pieces; *sectile*, when it can be shaved into fine slices; *malleable*, when it can be hammered thin; *elastic*, when a thin portion is bent it will fly back to the original position; *flexible*, when a thin portion can be bent without breaking.

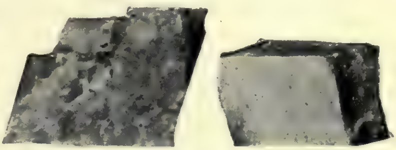

FIG. 2.—Cleavages: on the left calcite at oblique angles; on the right, feldspar at right angles (top and bottom). The end of the feldspar shows fracture instead of cleavage.

**Cleavage.** — When minerals split easily with smooth faces in certain directions they are said to have the property of cleavage. Thus some minerals, like quartz, when struck a blow, will break into fragments of various shapes. Others, like calcite, break into fragments each of the same general shape. When a mineral breaks easily and smoothly along certain planes it is said to have cleavage; for example, mica has a good cleavage in one direction. Calcite has three cleavages which are not at right angles. Feldspar cleaves in two directions nearly at right angles. (Fig. 2.) When it is present, cleavage is a very important characteristic.

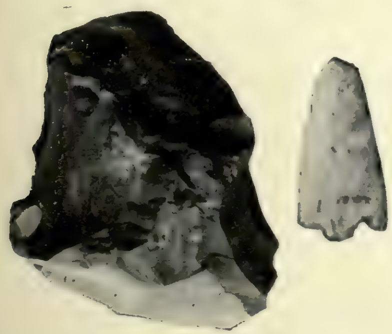

FIG. 3.—Shell-like (conchoidal) fracture of flint. To the right, an arrow head of the same material and with the same fracture.

**Fracture** is a break not along smooth faces as in cleavage. A fracture somewhat curved and shell-like as the inside of a shell is termed *conchoidal*, Fig. 3. This fracture is beautifully shown in some Indian arrow heads shaped from flint or chert. Fibrous minerals often show a *splintery* fracture. Some minerals have a *jagged* fracture like broken steel.

**Crystal form** is shown by many minerals. Quartz, for instance, often crystallizes into beautiful six-sided crystals. Calcite is commonly crystallized. Many minerals have both a crystalline and an uncrystalline form and some minerals have rarely or never been found crystallized. The general crystal form should, if possible, be recognized for it is constant for a given mineral.

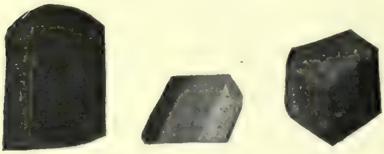

FIG. 4.—Crystal forms; from left to right, apatite, feldspar, garnet.

**Specific gravity** is an important characteristic of minerals. For many purposes, minerals may be described as follows:

Specific gravity up to 2, light; 2 to 4, medium; above 4, heavy. Quartz, having a specific gravity of about 2.7, may be remembered as a common medium-weight mineral.

## Important Soil and Rock-making Minerals

**Apatite** $(Ca_5F)(PO_4)_3$, a phosphate of lime, is essentially a combination of lime, phosphorus and oxygen. The mineral is very common in many granite-like (igneous) rocks where it may be found in crystalline form and the microscope shows that, in very small crystals, it is a common mineral of most igneous rocks.

The non-crystalline form often occurs in limestones, where it is the "phosphate" of commerce. In fact phosphate rock may be regarded as an impure limestone. The phosphorus in limestone is converted into soluble form by treatment with sulphuric acid. The crystalline form of apatite has the following characteristics:[1] H, 4.5–5; sp. gr. 3.17–3.23; luster, vitreous to resinous.

**Calcite** $(CaCO_3)$ is a combination of lime and carbonic acid. It is a very common mineral and is the basis of limestone. It is often crystallized and the crystals are commonly six-sided prisms and pyramids. The cleavage is perfect in three directions so as to form rhombohedrons. The mineral is brittle, commonly white, but often of various colors, including shades of red and brown. It is easily attacked by weak acids, forming carbon dioxide gas, hence effervescence upon application of acid is a rough test of

[1] H indicates hardness; sp. gr., specific gravity.

calcite and limestone. Calcite is fairly soluble in water which contains carbon dioxide, thus forming the bicarbonate which makes limewater "hard" for household use. Either in crystalline or amorphous forms it exists under many names among which are dog-tooth spar, limestone, chalk, calcareous marl, onyx, travertine, etc. **Aragonite** has the same composition as calcite but crystallizes in different forms; it is harder and heavier and cleaves into prismatic forms. The uses of calcite in the form of limestone are many; when limestone is roasted the carbon dioxide ($CO_2$) is driven off giving quicklime (CaO). It is used in glass making, iron smelting, and as a corrective for soil sourness. H, 3; sp. gr., 2.72.

**Dolomite** ($CaMg(CO_3)_2$) is a combination of calcium, magnesium and carbon dioxide. It much resembles calcite, from which it is distinguished by the fact that it does not easily effervesce in cold, dilute acid as does calcite. Nearly all limestones contain some dolomite but the term is usually restricted to those minerals having about 20 per cent or more of magnesium carbonate and the remainder of calcium carbonate. Limestones containing considerable dolomite are termed dolomitic limestones. They are usually somewhat better for building stone since they do not weather as readily as the pure limestones. Both calcite and dolomite are water-deposited minerals and are very frequent in many mineral veins where water has been an important depositing agent.

**Gypsum** ($CaSO_4 \cdot 2H_2O$) is a sulphate of lime combined with water. It occurs in crystalline form (*selenite*) or in a compact fine-grained form (*alabaster*) or as granular, earthy and often impure form known as *rock gypsum*. The crystalline form is a soft, clear mineral which can easily be split into thin, somewhat flexible plates. Most of the gypsum of commerce is obtained from the rock gypsum which, however, nearly always contains small crystals of selenite. When gypsum is heated in a closed tube it readily gives off its combined water. Gypsum is sparingly soluble in water and the principal deposits have been made by the evaporation of enclosed bodies of water. It is extensively ground and applied to the soil as "land plaster." When heated so as to drive off the combined water, gypsum becomes the "plaster-of-Paris" of commerce. Gypsum in crystalline form (selenite) has the following characteristics: H, 2; sp. gr. 2.31–2.33.

**Halite**, rock salt, "salt" (NaCl) is a combination of sodium and chlorine. It is a widely distributed and very soluble mineral, the qualities of which are so familiar as not to require description. Many coarse deposits are colored reddish shades by compounds of iron H, 2.5; sp. gr. 2.4–2.6.

**Nitre** ("saltpeter") ($KNO_3$) is formed by the action of nitric acid on compounds of potassium. It is a white, easily soluble mineral sometimes seen in thin crusts on walls and on decomposing animal and vegetable matter. The solubility of nitre makes it a quickly available potash fertilizer but its principal use is in the manufacture of explosives.

**Kainite** ($MgSO_4$, KCl, $3H_2O$) is a soluble mineral of variable composition. It is widely used as a potash fertilizer. The main supply is from Germany, where the kainite is associated with salt and other soluble minerals. The colors vary from white to red.

**Trona,** "black alkali" ($Na_2CO_3 \cdot NaHCO_3 . 2H_2O$) is a glistening, whitish, soluble, bitter mineral, known in our arid and sub-arid regions as "black alkali." It is an injurious mineral in soils; it puddles clays, is injurious to plants and it dissolves humus, forming a black solution which, upon evaporating forms black spots, hence the name.

**Mirabilite,** "glauber salt" ($Na_2SO_4 \cdot 10H_2O$), a soft, white light mineral (sp. gr. 1.5) which forms most of the "white alkali" of the arid regions. It is not a desirable ingredient in soils but is not so injurious as "black alkali." Both of these undesirable minerals are practically confined to soils in dry regions. They are brought near the surface by the action of ground water.

## Iron Minerals

Iron is only rarely found in the native state but in combination it is very widespread. The principal iron minerals are as follows:

**Hematite** ($Fe_2O_3$), an oxide of iron, occurs mainly in amorphous masses with reddish to reddish-brown colors and it always has a *red streak*. In rocks and especially in soils and subsoils it is widely distributed and is one of the causes of their reddish colors. H, 5.5–6.5; sp. gr. 4.5–5.3.

**Limonite** ($2Fe_2O_3 \cdot 3H_2O$) is an extremely common mineral. One of its common occurrences is "iron rust." It is yellowish to brownish in color sometimes compact but often earthy, when it is known as "ochre." Limonite is distinctively an alteration mineral, that is, it has been changed from some other mineral often by the addition of water. For example, one way by which limonite may be formed is by the addition of water to hematite according to the following equation:

| Hematite | added to | Water | yields | Limonite |
|---|---|---|---|---|
| $2Fe_2O_3$ | + | $3H_2O$ | = | $2Fe_2O_3 \cdot 3H_2O$. |

Limonite is the chief cause of the yellowish-colored tints of rocks and soils; its presence is an important factor in differentiating soils, not so much because of itself, but, as we shall see later, as an indicator of aeration and water circulation. It is an abundant ore but often impure. H, 5–5.5; sp. gr. 3.6–4 (both for the compact form only).

**Magnetite** ($Fe_3O_4$) is also an oxide of iron usually with metallic luster and black streak. It is often crystallized in cube-like forms and its common name, " loadstone," as well as its specific name suggest its prominent characteristic; it is strongly attracted by a magnet and is an important but not widespread iron ore. It is found in many crystalline rocks in microscopic crystals and so abundant is the magnetite in some boulders that they will deflect a compass needle. H, 5.5–6.5; sp. gr. 4.9–5.2.

**Siderite** ($FeCO_3$), is a carbonate of iron with colors varying through gray, brown to black. It is an important ore locally. H, 3.5 –4; sp. gr. 3.83.

**Pyrite** ($FeS_2$), is a sulphide of iron. The brassy yellow color has given the mineral its common name, " fools' gold." Pyrite is used only for its sulphur which is obtained by roasting. Its presence in iron ore in any but very small percentages renders the ore useless for most purposes. Pyrite is common in many rocks, where it is rather easily altered, an example being as follows:

| Pyrite | added to | Oxygen | and | Water | yields | Limonite | and | Oxide of sulphur |
|---|---|---|---|---|---|---|---|---|
| $4FeS_2$ | $+$ | $22.0$ | $+$ | $3H_2O$ | $=$ | $2Fe_2O_3 \cdot 3H_2O$ | $+$ | $8SO_2$ |

The oxide of sulphur thus produced changes to sulphuric acid ($H_2SO_4$), which vigorously attacks the rocks and breaks them down. Pyrite causes the " sulphur smell " in some coal smoke. H, 6–6.5; sp. gr. 4.9–5.2; streak, greenish black in contrast to the yellowish color.

## Silica and the Silicates

**Silica** ($SiO_2$) occurs in quartz, the crystalline form, and in amorphous forms such as flint, chert and chalcedony, which are non-crystalline. **Quartz** is hard and brittle, usually somewhat transparent and has a glassy luster. When crystallized, it shows six-sided forms, both prisms and pyramids. Some crystalline quartz with a certain purple color is the gem amethyst. Chalcedony and agate are non-crystalline forms. Flint and chert are more or less impure varieties and usually have a conchoidal fracture, a feature that, together with their hardness, made them valuable for primitive weapons.

Quartz is common the world over because it is a very stable and resistant mineral and our common sands are, therefore, predominantly of quartz. It is used as a filler for mortar and concrete, as an abrasive, in the manufacture of glass and has many other uses. Quartz is an important constituent of many rocks and is a very important constituent of most soils. Silica in various forms is extensively deposited by water in its slow underground movements. This is possible because silica is slightly soluble in alkaline solutions. H, 7; sp. gr. 2.7.

**The silicates** are extremely important rock-forming minerals. The name is applied from the fact that these minerals are various compounds of silica ($SiO_2$). In the silicates the silica acts as an acid radical in combination with a base. To take a familiar example, if hydrochloric acid is applied to lime we obtain a new compound of lime and chlorine, $CaCl_2$. In somewhat the same way we have, for example, a silicate, wollastonite, $CaSiO_3$, composed of calcium as the base and silica as the acid. A large and important group of silicates contain aluminum and are, therefore, termed aluminum silicates.

The **feldspars** are silicates of aluminum with bases of potash, soda and lime. The feldspars are hard, of medium weight and have two cleavages about at right angles. They are very important and widespread minerals in certain classes of rocks.

**Orthoclase,** the potash feldspar ($KAlSi_3O_8$), is of various colors ranging mostly from white to reddish tints. It is an essential mineral of granite and an important mineral in many other rocks. As a glaze for china and earthenware it has an extensive use. It is an extremely important soil mineral not only in soils from granite-like rocks in which it is a common mineral but also in many clay and silt soils in which it has been deposited. Orthoclase breaks down fairly easily in part because of its good cleavage which makes easier the work of ice and other agents. In decomposing, orthoclase yields sand, clay and some compound of potash. Soils which contain orthoclase have small bits scattered through them and these small particles are continually giving off soluble compounds of potash. Orthoclase has to a limited extent been ground and used as a fertilizer since it contains something like 17 per cent of potash. The mineral is regarded as the original source of most commercial potash. H, 6–6.5; sp. gr. 2.45–2.62; streak white; luster vitreous to pearly.

The **plagioclase feldspars** include **albite,** the soda feldspar, ($NaAlSi_3O_8$), **oligoclase,** the soda lime feldspar, **labradorite,** the lime soda feldspar and **anorthite,** the lime feldspar ($CaAl_2Si_2O_8$).

It will be seen that oligoclase and labradorite are mixtures of albite and anorthite. These feldspars are somewhat alike in appearance and their determination is often somewhat difficult. One feature rather common to the plagioclases is the fine striations often seen on the smooth cleavage faces. These feldspars decompose rather readily, yielding sand, clay and compounds of lime and soda.

**Micas** are characterized by the well-known perfect one-direction cleavage. **Muscovite,** white mica, commonly, but incorrectly, known as "isinglass," is a potash mica ($H_2(KNa)Al_3(SiO_4)_3$). **Biotite** is the black mica sometimes termed the iron-magnesia mica ( $(HK)_2(MgFe)_2Al_2(SiO_4)_3$). While the micas cleave very readily and so are easily broken into fine fragments, they do not readily decompose. As a consequence the mineral is widespread even in rocks that are not its primary source and a close examination of almost any handful of fine sand will reveal bits of mica. Since micas do not readily decompose they are not important soil minerals from the chemical viewpoint, but on the other hand, the fine flakes scattered through a soil render it more open textured. When mica is scattered through a rock its relative weakness aids in the breaking up of the rock into soils. In some rocks mica is so abundant locally that a considerable proportion of the stream "sand" is of this mineral. H, 2–2.5; sp. gr., 2.5–3; tenacity, elastic.

**Olivine** ($(MgFe)_2SiO_4$) is a glassy-appearing, brittle mineral of various colors. While not common in large masses it is widely distributed through many rocks. It changes readily to other minerals and thereby aids in breaking down a rock into soil. H, 6.5–7; sp. gr., 3.2–3.5.

**Hornblende** and **augite** are important rock-making minerals. They are much the same in composition but have different crystal forms. Both are shining black to greenish-black hard minerals and in composition are complex and somewhat variable silicates of lime, magnesium, manganese, iron, soda and potash. Augite, when well crystallized, is usually somewhat thicker and shorter than the hornblende crystals. Hornblende crystals are usually long and of needle-like appearance. These minerals are commonly somewhat massive in rocks and often cannot be readily differentiated.

Both hornblende and augite decompose rather easily, the former more easily than the latter because of its easier cleavage. Many "speckled granites" have hornblende as an important mineral. The rusty stains on some granites are due largely to iron oxides derived from decomposed hornblende. Hornblende has H, 5–6; sp. gr. 2.9–3.4.

**Secondary silicates** are derived from other silicates, when other compounds, especially water, are added to form new minerals. For example, olivine may, by the addition of oxygen and water, change to serpentine, a waxy-appearing mineral. The **zeolites,** usually light-colored minerals, are hydrous silicates with much combined water. The water is so weakly combined that slight heating will drive it off, hence the name from a Greek word meaning to boil, so called because these minerals swell and lose their water with an appearance of boiling when heated The following are among the zeolites of agricultural importance: apophyllite, a potash zeolite, $H_{14}K_2Ca_8(SiO_3)_{16} \cdot 9H_2O$; stilbite, $H_4(Na_2Ca)Al_2(SiO_3)_6 \cdot 4H_2O$; analcite, $NaAl(SiO_3)_2 \cdot H_2O$.

Zeolites are not widespread, although they are found abundantly locally. They occur typically in the crevices and cavities of some rocks. It is probable that they are somewhat common in many soils although their presence has not been definitely proved. They are rather unstable minerals and easily break down. It is a well-known fact that when a soluble salt, say soda, is introduced into a soil, the solution from the soil may contain potash instead of soda, evidently an exchange of bases. Hilgard and others hold that this exchange of bases takes place between soil zeolites. Furthermore zeolites are readily soluble and their bases are readily available for plants.

**Talc** ($H_2Mg_3(SiO_3)_4$), is a soft, light-colored mineral with a characteristic "soapy" feel. It is derived from magnesian silicates. **Serpentine** ($H_4Mg_3Si_2O_9$) is also a secondary mineral derived from silicates rich in magnesia. It is of variable colors with a somewhat waxy luster. Soils derived from serpentines are likely to be infertile and such area are sometimes called "serpentine barrens."

**Glauconite,** "greensand," is a hydrated aluminum silicate of iron and potassium containing also lime, magnesia and soda. It is usually in greenish grains, hence the common name "greensand." It is found in many formations but is especially abundant in the Cretaceous of the Coastal Plain. In the United States the most notable locality is in southern New Jersey. Glauconite has been used to some extent as a fertilizer on account of its potash and lime.

**Kaolinite** has the formula $H_4Al_2Si_2O_9$. It is an extremely important and widespread mineral and is the principal mineral of many clays which are so important a constituent of soils. Kaolin is entirely an alteration mineral resulting from the decomposition of silicates, especially the feldspars. When a feldspar, for example, breaks down, there results kaolinite, quartz and some compound of soda, potash or lime. The finer grades of porcelain are made from kaolin. Ordinarily, kaolin is light in color, somewhat crumbly and of light weight.

**Ferro magnesian** minerals, as the name implies, are those minerals, especially silicates, which are high in iron and lime. Such are hornblende, augite, biotite and olivine. It will be convenient to use this term frequently in later chapters.

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# CHAPTER II

## ROCKS

**Mantle Rock.**—Except in small and relatively rare areas, the earth's surface with which we are familiar is composed of loose, unconsolidated materials called the mantle rock, because it overlies the underlying or **bed rock** that is to be found the world over beneath this mantle rock. The upper part of this mantle rock, the part that supports plant growth, is the *soil.*

In ordinary usage the term rock implies a certain solidity and hardness, but in geological usage the term is broader and includes incoherent masses such as sand and clay as well as granites and other solid, hard rocks. It is mainly from rocks that the earth's history has been deciphered.

**Classification.**—It is evident that many different criteria might be used in the classification of rocks. They might be grouped according to origin or chemical composition or texture, or according to the predominant minerals; in fact all the above-mentioned criteria are used in the different classifications.

With respect to origin there are three great divisions. *Igneous rocks* have been cooled from a molten condition. *Sedimentary rocks* have been carried and deposited by wind, water or ice; the term is applied irrespective as to whether the sediments are loose or consolidated. *Metamorphic rocks* have been greatly changed, either chemically or physically. So far as their *chemical composition* is concerned, rocks may be divided into two classes. Igneous rocks with a high percentage of silica ($SiO_2$), 65 per cent or more, are termed *acidic;* those with high percentages of iron, calcium, magnesium or sodium are termed *basic;* basic rocks contain 50 per cent or less of silica. From the point of view of their physical composition, rocks may be classified according to their texture—whether the particles are coarse or fine-grained or whether they are easily seen or practically invisible.

## IGNEOUS ROCKS

Igneous rocks have been cooled from a former molten condition, an origin often revealed by features associated with flowing lava. Thus *flowage lines* which were developed by unequal flowage in the original lava are frequently reserved, and beds of porous lava and volcanic ash are sometimes found in ancient igneous rocks. One convenient classification is that by which igneous rocks are distinguished by the depth below the earth's surface at which they were cooled; deep seated igneous rocks are termed *plutonic,* while those formed at or near the surface as volcanic lavas are termed *extrusive.* But while these rocks differ in some respects, it should be remembered that they grade into each other and in geology as in other sciences there are few, if any, sharply dividing lines. Another useful term is *magma,* by which is meant the former molten condition of igneous rocks. The term is closely synonymous with the term lava, but the latter term is usually restricted to modern surface flows. Obviously the volcanic lavas recently erupted are easily studied; on the other hand, erosion has not only worn down volcanoes so their interior structures can be studied, but it has exposed to observation deep-lying plutonic masses, Fig. 22. Igneous rocks are considered to be the primary rocks from which all others have been derived, either directly or indirectly, and they, therefore, naturally come first in the study of rocks.

**Composition.**—While the number of elements in most igneous rocks is small, the number of possible combinations is large. However, the prominent and important minerals are relatively few. The following table is an estimate, based on a great many analyses, of the average mineralogical composition of igneous rocks:[1]

| | | | |
|---|---|---|---|
| Feldspar | 59.5% | Biotite | 3.8% |
| Minerals of the hornblende and augite class | 16.8 | Titanium minerals | 1.5 |
| Quartz | 12.00 | Apatite | 0.6 |

The large amounts of apatite and feldspar are of agricultural interest since the igneous rocks are probably the principal original source of our phosphorus, potash, lime and soda. It will be seen that the minerals of igneous rocks are largely silicates, which are combinations of silica ($SiO_2$) with various bases. For example, if the magma of an igneous rock is high in potassium it may contain considerable orthoclase feldspar; if high in magnesium and iron, olivine is likely to be formed; if

[1] F. W. Clark, Bulletin 330, U. S. Geological Survey.

low in silica but high in iron, magnesium and calcium, the predominant minerals are likely to be ferro-magnesian. When the magma is high in silica, some of the silica cannot come into combination since there are not enough basic materials and free quartz will therefore separate and crystallize by itself.

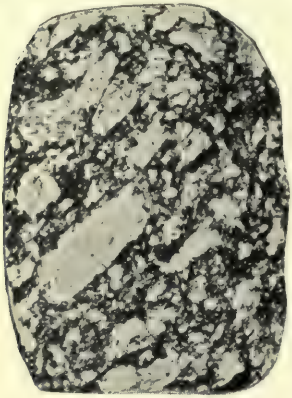

FIG. 5.—Granite showing granitoid texture. (Daly, Canadian Geological Survey.)

**Texture** of an igneous rock depends primarily on the rate of cooling. The solution of salt in water is an analogy; if this solution is allowed to evaporate slowly, large, distinct grains may be formed, but if the evaporation is rapid, the result is a more or less amorphous mass of salt. Similarly, if a magma cools slowly under favorable circumstances, the elements assemble into minerals which crystallize and form a mass mainly composed of interlocking crystals either large or small. Such a texture is termed a *granitoid texture,* of which granite is a well-known example, Figs. 5 and 6. If, on the other

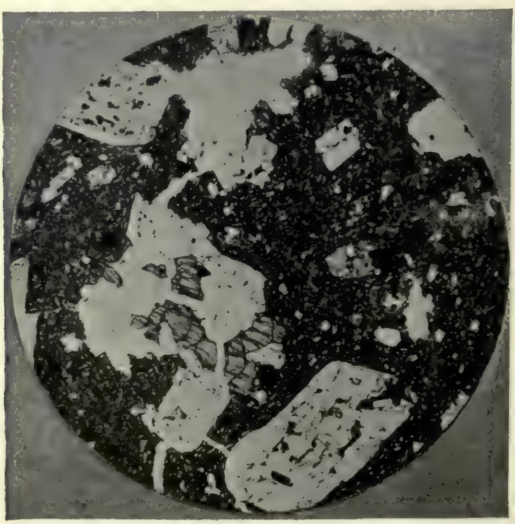

FIG. 6.—Granitoid texture. A microphotograph of a thin section of igneous rock, highly magnified. The light-colored minerals are mostly feldspars. (U. S. Geological Survey.)

hand, the cooling is rapid, there are no definite minerals crystallized and the resulting rock is amorphous and glassy. Such is termed a *glassy texture,* Fig. 7. Glass and furnace slag are examples of glassy textures. Under certain conditions some of the minerals will crystallize into definite crystals termed *phenocrysts* and the remainder of the magma will remain glassy or composed of very fine crystals; the latter portion is termed the *ground mass.* Such a texture is termed *porphyritic,* Fig. 8.

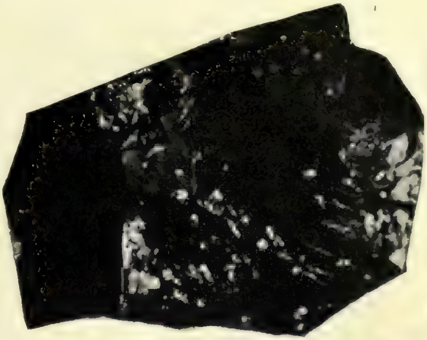

Fig. 7.—Glassy textures of obsidian.

While the rate of cooling is the primary factor in the production of texture, other factors have a more or less indirect influence. (1) Pressure and dissolved vapors such as steam have some effect. (2) Temperature obviously is important for, in general, the higher the original temperature the more time is consumed in cooling with a resulting tendency towards a coarser texture. (3) The composition of the magma is important since the melting varies with the composition. The most acid or siliceous magmas are least fusible and the more basic are more fusible. Hence it is that highly siliceous rocks will more quickly chill, and other things being equal, tend towards glassy or porphyritic textures while the basic rocks chill less easily and tend towards the porphyritic and granitoid textures. For this reason basic lavas tend to flow farther from the vent than acid lavas. (4) It is evident that deeply buried plutonic magmas will produce rocks with coarser texture than extrusive rocks. Very commonly an old lava flow will show glassy texture at the margins, porphyritic texture for a distance within and at the center will be found granitoid textures, the difference being due to different

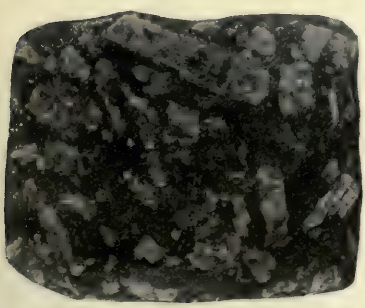

Fig. 8.—Porphyritic texture. The light-colored phenocrysts of feldspar are imbedded in a dark-colored mass.

rates of cooling. Finally it should be remembered that there are all gradations between textures because there are all gradations between the factors producing textures.

**Classification** of igneous rocks is made on a threefold basis according to *texture*, *minerals* and *chemical composition.* Any magma, acid or basic, may have any texture, although as we have seen some magmas favor certain textures according to circumstances. Two magmas may have the same chemical composition but different minerals, as, for example, one rock may contain hornblende and the other augite, both minerals having substantially the same composition but different forms. It is convenient to designate certain minerals as *essential minerals* when they are characteristic of a certain rock while all others are termed *accessory minerals.* By the use of the microscope in rock determinations a large number of minerals have been described and named, but the close distinctions made possible by this method constitutes the work of the trained geologist and is of little use to the average field worker. For ordinary purposes, a method of classification in considerable use is based on easily recognized features such as color, texture and a small number of easily distinguished minerals. Sharp distinctions are often not possible and in some cases identifications must be made by more elaborate methods.

## Descriptions of Igneous Rocks

**Granitoid Texture.**—The igneous rocks with granitoid texture and minerals that for the most part can be distinguished with the unaided eye include granite, syenite, diorite and gabbro.

**Granite** has a granitoid texture with quartz and feldspar as the essential minerals. Mica is usually present and mica and hornblende are the most common accessory minerals. Granites are formed from a somewhat siliceous magma since there must be an excess of silica which crystallizes as quartz. When accessory minerals are in considerable quantity, the name of the principal accessory minerals is placed as a prefix to the rock name, as for example, hornblende granite or muscovite-biotite granite, etc. Apatite is nearly always present but in small quantities and usually in grains of microscopic size. Granites with no accessory minerals are termed *binary* granites.

In general, granites are light-colored rocks, the colors being largely due to the feldspars since the quartz is generally colorless. Reddish feldspars afford the pink and red granites of commerce. A preponderance of muscovite with light-colored feldspars gives gray or white granite. There is naturally a wide variation in the texture of granites ranging from fine to very coarse grains. A *pegmatite* is a coarse-grained granite which sometimes yields large sheets of mica and is the main source of orthoclase.

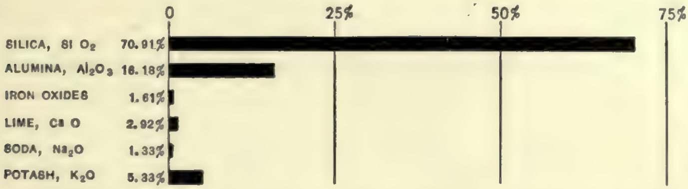


Fig. 9.—Diagram showing the chemical composition of a biotite granite. (After Daly, Canadian Geological Survey.)

Granite is the best-known igneous rock because of its wide use as a building stone. Its ease of quarrying and working, attractive colors, durability and high crushing strength make it desirable for construction purposes. Fine-grained varieties are used for statuary. It should be remembered that, somewhat unfortunately, the term granite is commonly applied to all igneous rocks that are used commercially.


Fig. 10.—Mineralogical composition of a biotite granite. (After Daly, Canadian Geological Survey.)

Fig. 9 shows the chemical composition of a biotite granite and Fig. 10 the principal minerals. It will be seen that silica comprises nearly three-fourths of the entire rock and yet only about one-third is free quartz. It will be noted, however, that most of the minerals are silicates so that the silica is combined and not free as quartz. The potash combines with the alumina and silica to form orthoclase and the lime and soda, in like manner, combine to form the plagioclase feldspars. The biotite mica results from a union of iron and other bases with alumina and silica. It will be noted that, for some unknown reason, all the iron did not combine but a small amount separated to form the oxide magnetite. The rock is light gray in color.

**Syenite** consists of feldspar with little or no quartz and usually small amounts of hornblende or mica. It resembles granite in general appearance and often a somewhat careful determination is required to determine the absence of quartz, especially if the rock is finely crystal-

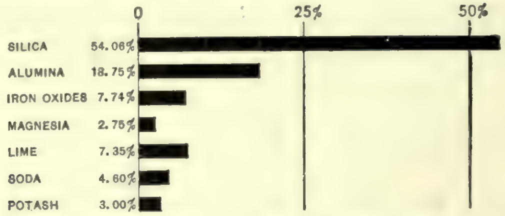


Fig. 11.—Diagram showing the chemical composition of a syenite. (After Daly, Canadian Geological Survey.)

lized. It is not an important rock so far as surface exposure is concerned.

Figs. 11 and 12 show the chemical and mineralogical composition of a basic syenite, that is, a syenite with high content of iron and other bases. Practically all the silica has combined with alumina and bases to form silicates and less than 1 per cent has crystallized as quartz. Many syenites have a higher percentage of quartz and grade into the granites.

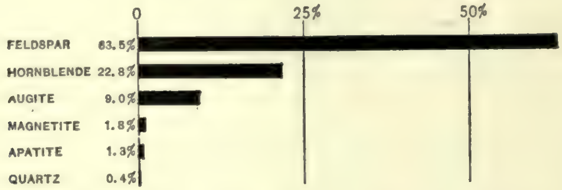


Fig. 12.—Diagram showing the mineralogical composition of a syenite, the chemical composition of which is shown in Fig. 11.

A marked contrast with granite is the high feldspar content. The ferro-magnesian minerals, hornblende and augite, are due to the high percentage of iron and other bases and it will be noted that here, again, some iron remained uncombined and crystallized as the magnetic iron oxide, magnetite. The potash combines to form orthoclase feldspar. This rock shows a high content of apatite. From the predominance of the accessory ferro-magnesian minerals, the rock is termed a hornblende-augite syenite.

**Diorite.**—This is a rather common dark-colored rock. It consists essentially of hornblende and feldspar, and it often contains minor quantities of quartz and biotite. It is a rock somewhat intermediate in composition between the acid and the basic rocks. While the texture is granitoid, yet the mineral grains are usually small and the rock fine textured and compact, so that it is frequently difficult to identify a

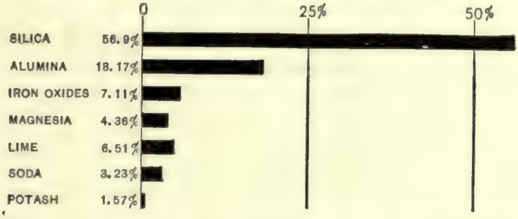


Fig. 13.—Chemical composition of a diorite. (After Daly, Canadian Geological Survey.)

diorite without a microscopical examination. They are often called "greenstones" because of their frequent greenish-black color. Like many other dark siliceous rocks, diorite is sometimes called "trap rock."

Figs. 13 and 14 show the compositions of a diorite. As compared with the granites, the silica and potash have decreased, and with the practical absence of potash, the orthoclase has disappeared. The higher lime and soda account for the predominance of labradorite. The

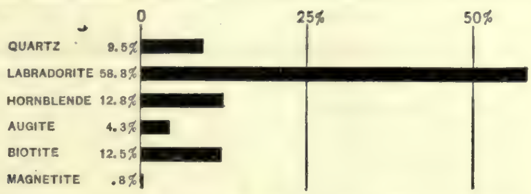


Fig. 14.—Mineralogical composition of a diorite, the chemical composition of which is shown in Fig. 13. (After Daly, Canadian Geological Survey.)

high iron and other bases combine to form the ferro-magnesian minerals hornblende, augite and biotite. The reason for the small amount of quartz as compared with granite is that the magma had a small silica content and hence there was a smaller amount of uncombined silica to separate as free quartz. The rock is usually dark brown to greenish-gray in color.

**Gabbro.**—This rock is usually dark in color, coarse grained and heavy. Gabbros are derived from magmas that are relatively poor in silica and potassium while richer in iron, magnesia and lime. From this composition it will be seen that the predominating feldspars would be the lime feldspars, labradorite and anorthite. Magnetite is usually present and gabbro boulders sometimes contain so much magnetite as to deflect a delicate magnetic needle. Apatite and olivine are common while quartz is naturally low in quantity. Their granitoid texture

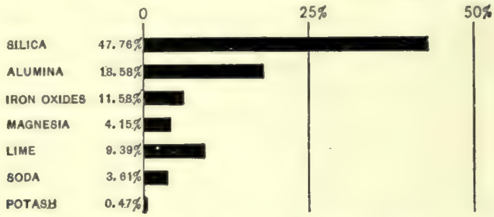


FIG. 15.—Chemical composition of a gabbro. (After Daly, Canadian Geological Survey.)

indicates slow cooling deep in the earth's crust and therefore the gabbros are distinctively plutonic rocks. They are easily recognized but not widely distributed rocks.

Figs. 15 and 16 show the compositions of a gabbro. The silica is low and is mostly combined. The high lime and soda account for the labradorite, which constitutes over half of the rock. The high percentage of hornblende and augite is explained by the abundance of iron

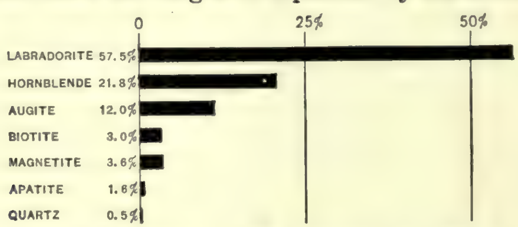


FIG. 16.—Mineralogical composition of the gabbro, the chemical composition of which is shown in Fig. 15. (After Daly, Canadian Geological Survey).

and magnesia. The rock is termed a hornblende-augite gabbro and is grayish in color and heavy.

**Porphyritic Texture.**—It will be remembered that, under some conditions, magmas cool so that some minerals are able to crystallize while other minerals are unable to crystallize. A rock formed under such circumstances is termed a **porphyry** and the distinguishing prefix to the name is that of the dominant phenocryst. For example, if most of the phenocrysts are quartz the rock is a quartz porphyry; if of feldspar, the rock is a feldspar porphyry, Fig. 8. Porphyries usually have a mottled appearance since the ground mass and the phenocrysts are ordinarily of different colors.

**Felsitic Texture.**—Some igneous rocks have a crystalline texture, but the crystals are too small to be visible. Such a texture is intermediate between the granitoid and the glassy textures and is termed *felsitic texture.* The light-colored rocks with this texture are called *felsites,* the dark-colored rocks are called *basalts.*

**Felsites** are stony-appearing rocks of moderate weight. Grays, yellows and reds are common colors. They are usually hard rocks and break with a conchoidal fracture. Certain felsites called rhyolites have a wide distribution and often show flowage lines and other features common to lava flows. Most felsites are of acid or intermediate composition.

**Basalts** are heavy, dark-colored, dense and somewhat basic rocks of felsitic texture. In composition they are similar to the gabbros. They are derived from somewhat basic magmas which fused easily and flowed readily. Basalts are very common volcanic rocks and are now ejected by many modern volcanoes. The vast lava flows in Oregon, Idaho and Washington (Fig. 28) are mostly composed of basalt. Basalts often show cavities due to expanding gases and these cavities sometimes have minerals deposited in them. Some of the copper deposits of Michigan consist of copper in such cavities. In texture the basalts are typically fine grained, although there is considerable variation. A deep basaltic lava flow, for example, may be felsitic in the upper part and somewhat porphyritic in its lower portions. The color varies from gray to dark. The term is somewhat inclusive and includes many dense, hard, heavy igneous rocks. Trap is a term also applied to this rock.

**Glassy Rocks.**—These rocks are formed by a quick chilling of their magmas so that practicallly no minerals crystallize. In general, rocks of this texture are likely to be of acid composition, for it will be remembered that siliceous magmas fuse with difficulty, and therefore chill readily. Moreover, rocks with glassy texture are largely confined to flows at or near the surface since here it is that magmas are so quickly cooled that glassy textures usually result. Furnace slags are essentially basic glasses and often cannot easily be distinguished from volcanic glasses.

**Obsidian** is the general rock name applied to most rocks of glassy texture. The colors range through black, brown to red with black as the most common color. **Pitchstone** resembles obsidian but has a somewhat resinous or pitch-like luster. Obsidians are hard, usually brittle and break with a conchoidal fracture, Fig. 7. **Pumice** is a spongy, cellular lava; the cavities are due to steam expanding when the rock was erupted. Pumice will float, often for months, and has been found in deep-sea dredgings in many different localities.

### Classification of Igneous Rocks (after Pirsson)

A. Granitoid Texture. Minerals Recognizable

Generally light-colored rocks. Generally dark-colored rocks high in ferro-magnesian minerals.

| | | | |
|---|---|---|---|
| Quartz and feldspar. *Granite.* | Feldspar with little quartz. *Syenite.* | Ferro - magnesian minerals and feldspars. *Diorite.* | Ferro - magnesian minerals with small feldspar content. *Gabbro.* |

B. Porphyritic Texture. Minerals Mostly Recognizable

*Porphyries*

C. Felsitic Texture. Finely Crystalline. Minerals Mostly Unrecognizable

| | |
|---|---|
| Light-colored rocks. *Felsite.* | Dark-colored rocks. *Basalt.* |

D. Glassy Texture

*Obsidian*

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## OCCURRENCES OF IGNEOUS ROCKS

At this point it will be of interest to consider some of the forms of igneous rocks and their modes of occurrence, for the rocks on the one hand and their various occurrences on the other hand help to explain each other. We have noted the division of igneous rocks into two classes, the *extrusive,* in which lavas are poured out on the earth's surface or on sea bottoms, and the *intrusive,* in which magmas (see page 17), are forced into rocks beneath the surface. Since vulcanism is considered in a following chapter, it will be sufficient at this point to state that extrusive rocks are due to volcanic agencies and defer discussion to following pages.

INTRUSIVE FORMS.—By far the largest areas of known igneous rocks have not been extruded as volcanic lavas, but have been forced into rock far beneath the earth's surface and are now exposed only by the erosion of formerly overlying rocks. It is convenient to recognize different forms and shapes although they often grade into each other and, furthermore, portions exposed to observation are often too small for the form or shape to be determined. Some of the more common forms are *dikes, sills, laccoliths, bosses, stocks* and *batholiths.*

**Dikes** are essentially more or less vertical fissures which have been filled with lava which has solidified. When they are intruded into sedimentary rocks, they typically break *across* stratification planes, Fig. 18. They range in thickness from a fraction of an inch up to hundreds of feet and a length of over one hundred miles has been traced. Dikes are often interrupted and reappear and they commonly form branching systems which are in places very complex. In some instances lava has reached the surface and flowed out from a fissure and when the lava cooled in the fissure a dike was formed; such dikes often are found in the sides of a volcano. On the other hand, many deep-lying dikes can be seen only when the overlying rocks have been eroded.

A dike is often of relatively resistant rock and, therefore, breaks down less rapidly and makes somewhat high land. This is especially the case when dikes occur in sedimentary rocks. Moreover, most dikes are relatively thin and cool somewhat fast so that their texture is glassy and this texture is usually more resistant than other textures. In some cases dikes may extend as a wall-like mass, as seen in the Spanish Peaks region of Colorado, Fig. 17. However, a dike is perhaps more often marked by a range of hills than by a ridge. Occasionally a dike is less resistant than the adjacent rock, especially if intruded into igneous rock and in such a case the dike is often marked by a trough-like depression. This is often well shown on some sea coasts where dikes

Fig. 17.—The great dike, Spanish Peaks Region, Colo. The dike was formerly enclosed by sedimentary rocks which have been eroded. (Hill, U. S. Geological Survey.)

are eroded by the waves and long fissures are formed which extend back from the shore. Many dikes when they occur in mountainous regions are necessarily of little agricultural interest, but in a belt of sandstones and shales (Triassic) which extends from New Jersey to North Carolina, the dikes are of considerable importance. A somewhat typical occurrence in this region is shown in Fig. 18 where a dike has been intruded into shales. The dike is marked by a line of low hills, one of which, however, rises to a considerable height as "Round Top," the hill made famous in the Battle of Gettysburg. The dike rock yields a clay loam

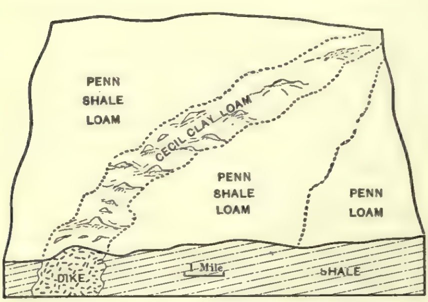


Fig. 18.—Diagram of a dike intruded into shales. The shales yield loams and the dike, a clay loam. (Data from U. S. Bureau of Soils.)

(Cecil),[1] but in this as in so many other instances the greater elevation of the dike country promotes erosion, which tends to make the soils coarse textured. Many dikes which are not topographically distinguished can be traced by their derived boulders, often reddish in color, which strew the surface.

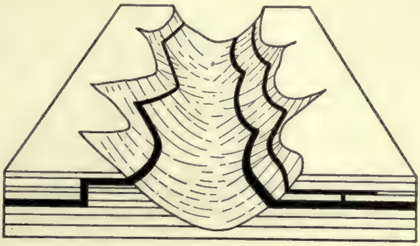

FIG. 19.—Diagram showing sills and dikes. The sill on the right has broken across a stratum and branched.

**Sills** are somewhat like dikes except that they are more or less horizontal and typically are intruded *between* strata although they may cut across one stratum and be continued in another, Fig. 19. Sills are best developed in sedimentary and other rocks which are readily penetrated

[1] A *soil series* is a group of soils having, in general, the same origin and similar essential characteristics. A *soil type* is a minor division including soils having the same mechanical composition. For example the Cecil series are derived from granites an. gneisses and are found in the northern Piedmont. The soils are gray to red in color and are underlain by red clay subsoils. The soil type, Cecil clay loam, is one of the soil types belonging to the Cecil series and having the mechanical composition of a clay loam as shown below.

Soils are divided according to their mechanical composition as follows, the average diameter of soil particles being given in millimeters (1/25 inch):

| | |
|---|---|
| Sand | 1–.05 mm. |
| Silt | .05–.005 mm. |
| Clay | below .005 mm. |

The following soil classes are commonly recognized. (Averages determined from 8664 mechanical analyses; Bull. 78, U. S. Bureau of Soils, 1911, page 12.) Sands and sandy loams are called "sandy" or "light soils"; silts and silt loams are called "heavy soils."

| Sands. | Sand and Fine Gravel, Per Cent. | Silt, Per Cent. | Clay, Per Cent. |
|---|---|---|---|
| Sandy loams | 67 | 21 | 12 |
| Loams | 44 | 40 | 16 |
| Silt loams | 20 | 65 | 15 |
| Clay loams | 36 | 38 | 26 |
| Silty clay loams | 14 | 61 | 25 |
| Clays | 22 | 36 | 42 |

by the invading molten materials, and like dikes, they often branch and subdivide in a complex fashion. Sills are often cut by dikes and both dikes and sills manifestly grade into each other. Sills and the adjacent strata are often tilted or folded and thus give rise to ridges and escarpments of which the well-known Palisades along the Hudson are an example, where a thick sill has been uplifted and forms the escarpment shown in Fig. 20. Sills and dikes are common features in a belt of sand-stones and shales which, with some interruptions, extends from the Connecticut Valley into North Carolina. When the sills and dikes stand up as ridges, the soils are usually thin and stony but when they are well worn down the soils are typically deep, reddish and somewhat heavy in texture.


Fig. 20.—The Palisades, a sill, N. Y. Distant view above; close view, middle. (U. S. Geological Survey.) The diagram below shows the general structure in the vicinity.

**Volcanic necks** are remnant cores of old volcanoes. They are commonly formed as follows. A volcano is built up of fragmentary materials and lava and when eruptions cease the lava chills and hardens in the vent so as to form a kind of pillar, so to speak, in the volcano. As erosion goes on the weaker outer materials are worn away, leaving the more resistant central core projecting. There are all stages from the fresh volcano, where the core is not yet exposed, to instances where the weaker materials around the plug have been worn away and, indeed, the plug itself has almost disappeared.

Volcanic plugs are found in many localities, among them the coastal plain of Texas. Pilot Knob, a low, rounded hill near Austin, Tex.,

Fig. 21, is an example. Here was formerly an active volcano which has been so thoroughly reduced by erosion that only the filled throat remains. This is composed of a dark basalt which yields a heavy clay soil with numerous boulders.

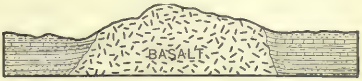


Fig. 21.—Pilot Knob, Texas, a volcanic plug. (After Hill, U. S. Geological Survey.)

**Laccolith.** — When a mass of molten rock is so intruded beneath strata that they are arched into a dome-shaped elevation, the intrusion is termed a laccolith; it is really a special form of a thick sill. Sundance Mountain, Fig. 22, is an interesting example where the arched overlying beds above the intrusion have been entirely removed by erosion and the

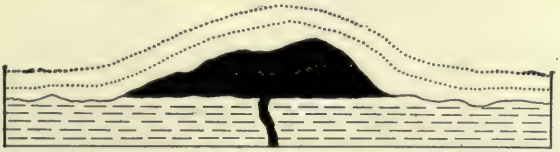

Fig. 22.—Sundance Mountain, Wyo., a laccolithic mountain (Upper photo). The sides of the mountain are partly buried in waste. The diagram below shows a mass of lava (black) which was intruded beneath overlying rock and arched it upwards. The overlying sedimentary rocks have been eroded so that the intruded lava now forms the mountain. (After Darton, U. S. Geological Survey.)

intrusive porphyry is seen resting on sedimentary rocks. The laccolith has been eroded to its very roots, so to speak.

**Stocks** or **bosses** are irregular masses of intruded igneous rocks, often with rudely circular or elliptical surface exposures. They vary from a few hundred feet to several miles in diameter. **Bathyliths** are much the same except that they are much larger and their surface exposures often include thousands of square miles; they form the core of many mountain ranges. Probably these intrusive masses attained their present positions by melting and assimilating the adjacent rocks, although naturally our knowledge of the method of their intrusion is indefinite. These huge masses are usually exposed only by the erosion of formerly overlying rocks.

## Vulcanism

**Volcanoes** are at once the most spectacular of geological agencies. A volcano is not necessarily a mountain, but given a vent from which lavas, cinders and other materials escape, a mound or cone will ordinarily be built. Typically, however, a volcano is a conical hill or mountain. The lavas of many modern volcanoes are somewhat basaltic, or in other words somewhat basic in composition and in cooling they often form a somewhat porous basalt. Naturally, the lavas cool so quickly that they never assume the granitoid texture, but many volcanic basalts are porphyritic and some lavas, even when escaping from the crater contain crystallized minerals.

**Ejecta from Volcanoes.**—From an agricultural viewpoint volcanoes have considerable interest since there are large areas of soils that are derived directly from lavas. But even more important is the widespread volcanic dust which has been scattered by winds so that these fine materials undoubtedly are incorporated in many soils. **Vulcanism** treats primarily of the movements of lava and associated materials and for our purposes will be considered under two heads, *volcanoes* and *fissure flows*.

Three classes of materials are ejected from volcanoes, namely, lava, gases, and fragments (pyroclastic materials). **Lava** is a molten material which may be regarded as a solution of minerals; for example, we might say that a lava, which under certain conditions would cool to a granite, is a solution of quartz, feldspar, mica and hornblende, the whole mass made fluid by heat.

As we have seen, lavas vary greatly in fluidity, some flowing a considerable distance while others become chilled and stiff soon after being ejected. The lavas which flow for long distances and cover large areas are largely basic in composition, a highly fortunate circumstance since basic lavas in general yield better soils than siliceous lavas.

Many *gases* escape from volcanoes of which by far the most important is steam. It has been estimated that a small cone on Mt. Ætna in Sicily ejected in one hundred days 2,100,000 cubic meters of water and this was only a small fraction of the total water ejected from this volcano. This amount of water is about the estimated flow of the St. Lawrence River for one second. In eruptions where large quantities of steam are ejected, the steam rises, is condensed, and mingling with volcanic dust and cinders, descends as the dreaded hot mud. This mud when somewhat hardened forms *tuff*, which is an important soil former in places. Many volcanoes eject enormous amounts of carbon dioxide.

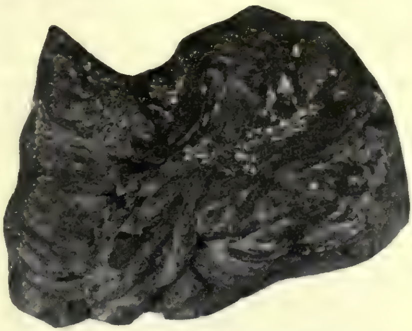

FIG. 23.—A volcanic bomb.

The *solid matter* ejected from volcanoes consists of fragments of hardened lava which are blown out by the expansion of gases. In

FIG. 24.—Castle Rock, Nebraska. Note the white volcanic dust at the base of the hill. (Darton, U. S, Geological Survey.)

violent eruptions large blocks of hardened lava are thrown for great distances. Smaller fragments, Fig. 23, are variously termed according to size; *lapille* are about the size and shape of nuts and *bombs* have a roundish shape about the size of an apple. *Volcanic sand* and *cinders* are terms that are self-explanatory. Still finer is *volcanic dust*, which will float in the air for days or weeks.

*Scoria* and *pumice* are cellular and porous masses of lava; when they were ejected as lava, the confined steam expanded and produced their characteristic structure. All these fragments, as one would expect, are typically larger near their source and grade to finer materials at a distance, although the grading is very imperfect.

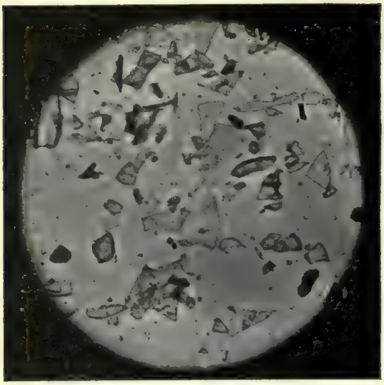

Fig. 25.—Very fine volcanic dust, Nebraska. Magnified about 250 diameters. It is largely composed of angular bits of glass.

From an agricultural point of view, the finer dust is the most important of these fragments because it is carried so far by the winds and spread on the soils. Widespread formations in Nebraska and adjacent states contain beds of volcanic dust the origin of which is unknown, but there are no probable sources within hundreds of miles, Figs. 24 and 88. Every eruption where dust is ejected furnishes materials that finally settle on soils and become more or less incorporated in them. It is no exaggeration to state that millions of acres have an appreciable amount of volcanic dust in their soils and, indeed, it is probable that nearly every square mile of the earth's surface contains some volcanic dust. In many cases volcanic dust has settled in lakes and forms beds of considerable thickness. The Florissant beds of Colorado were thus formed and in these beds are preserved remarkably perfect fossil insects. A further illustration is found in lake beds located in the Jefferson River Valley of Montana. Here heavy showers of white volcanic dust settled to the bottom of lakes. Upon this is a stratum over 1000 feet in thick-

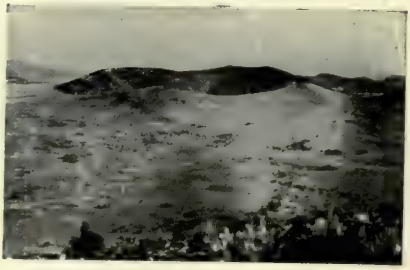

Fig. 26.—Crater of an extinct volcano in Arizona. (Robinson, U. S. Geological Survey.)

ness composed of reddish volcanic dust which was evidently washed into the lake from the surrounding basin. Furthermore, there are, in many places, considerable areas of soil-producing rocks which were once volcanic materials but which have become altered by metamorphism.

FIG. 27.—A recent lava flow in New Mexico. The surface has a "ropy" appearance due to unequal flowage. (Meinzer, U. S. Geological Survey.)

**Types of Eruptions.**—It is convenient roughly to divide volcanoes into two types, *explosive* and *quiet*, according to the character of the eruptions. It must be noted, however, that not only do these types grade into each other but the same volcano may at different times belong to the one or the other type. The explosive type, as the name implies, is characterized by violent expansion of gases by which fragments are sometimes thrown to great distances. Vesuvius is perhaps the best-known example of this type, but by far the most notable example is Krakatoa, a volcano in the East Indies. In 1883 this volcano ejected enormous quantities of dust high into the air and this dust was carried around the world by the upper air currents and is believed to have been the cause of the extraordinary red sunsets in the autumns and winter of 1883–84. Mauna Loa and Kilauea, two volcanoes of the Hawaiian Islands, are examples of the quiet type. The lava gradually fills the craters and its pressure usually develops fissures through which the lava escapes and pours out in comparatively gentle floods. In the quiet type but little fragmentary material is ejected.

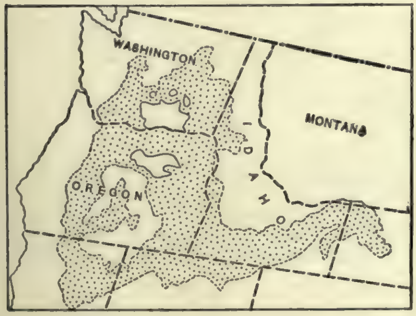


FIG. 28.—Map of the Columbia River lava flows (dotted areas.)

**Fissure flows,** as the name implies, are lava flows from a fissure instead of from a volcanic vent. Here again, however, the distinction is not close since small cones are usually scattered along a fissure. Indeed some geologists believe that some ancient flows were ejected for the most part from a line of very low volcanoes instead of from

FIG. 29*A*.—View over the Columbia lava plateau in the Palouse district, Washington. Alfalfa in foreground. (Curtis, courtesy of Professor Henry Landes.)

FIG. 29*B*.—View of the Grand Coulée, a valley cut in the Columbia lava plateau, Washington. (Curtis, courtesy of Professor Henry Landes.)

fissures. In the great eruption of 1783 in Iceland, a flow of lava welled from a fissure 20 miles long with a flow in places 68 miles wide. This type of eruption is rare at present, but was very important in earlier geological periods. In a relatively recent geological period (Tertiary), great floods of lava overspread an area in Oregon, Idaho and Washington estimated at over 200,000 miles in extent and with an observed thickness in places of hundreds of feet, Fig. 28. The plateau of the Deccan in India has an even larger area of lava ejected largely from fissures. Such widely extended lava flows must have been made by extremely fluid lava which is largely basic, as we would expect from our discussion on a previous page of the relation between composition and fluidity. There are but few fragmentary materials thus indicating a quiet type of eruption.

The lava flow in the Northwest was not continuous but a succession of flows, as is proved by the buried soils and sediments. The lava extended up valleys and around hills much as a flood of water. In places some of the flow features are well preserved but on the level areas the easily decomposed basalt has weathered to a deep, productive soil, which under favorable moisture conditions is very fertile.

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## CLASTIC (FRAGMENTAL) ROCKS

**Clastic rocks** are derived from the debris of other rocks and, for this reason, they are often called *fragmental* rocks. Moreover, since they are for the most part deposited as sediments they are often termed *sedimentary* rocks. It is a matter of common observation that even the hardest rocks, as granite for example, will break up into fragments under the attack of the weather and thus the materials for clastic rocks are furnished. The materials of these rocks are relatively simple since they usually represent a final stage in the decomposition of the parent rock. A sandstone derived from a granite, for example, is largely composed of the quartz that is left after the granite has thoroughly decomposed.

### The Agents

The **agents** involved in the formation of clastic rocks are many and their effects will be considered in greater detail in later chapters. By far the most important of these rocks are those deposited by water. The sand, clay and other materials derived from the breaking up of other rocks are carried by streams, and for the most part, they are finally deposited in the ocean. The faster currents carry the heavier and coarser fragments and the slower currents the finer fragments. The waves and the beach currents also sort the materials along the shore zone. As a result, sediments are often *stratified*, that is, they are arranged more or less in layers, the coarser and heavier having been deposited by swift currents while the finer sediments were deposited by slower currents. For example a river flowing into the sea would, in flood, deposit a sandy stratum, and at low water, a stratum of clay. Not only so but the waves and shore currents might modify and rework the sediments. Thus so many clastic rocks show stratification that this feature is somewhat distinctive of this class of rocks, Fig. 30.

FIG. 30.—Stratified rocks. The projecting ledges are limestone; the others are shale. (U. S. Geological Survey.)

Since most sedimentary rocks have been deposited in the ocean, they are said to be *marine* in origin. This compels a modification of the common ideas as to the stability of the lands for much of North America has been repeatedly elevated and depressed below sea level. It must also not be forgotten that important formations have been laid down in lakes or even in shallow swamps and that some rocks are of wind origin, but the most extensive and important sedimentary formations are of marine origin. Furthermore, it is important to note from the viewpoint of soils that the great soil-forming formations are mostly sedimentary rocks.

The study of deposits in oceans and other waters therefore gives clews to the formation of ancient sedimentary rocks. The coarser materials, such as sand and gravel, are generally deposited near the shore, for here wave action is strongest and, moreover, the streams drop their heaviest load near shore. Weaker currents carry finer materials such as fine sand, silt and clay out to greater depths and more quiet water.

Hence it is that one may often trace a stratum or formation from conglomerates and sandstones formed near shore through shales which were deposited in deeper water to limestones which were accumulated in clear and quiet water at a distance from land. It must not be assumed, however, that such gradations are the rule, for there are numerous exceptions because of changing conditions of deposition.

Among other agents winds may also carry and deposit fine materials and their deposits often show stratification but to less extent than water deposits. Glaciers have made such vast surficial deposits that they will be considered in a later chapter. Chemical precipitates occur to a limited extent in the oceans and to a considerable extent in closed bays and lakes, as, for example, when the water evaporates from a lake or closed bay, the materials in solution, mostly common salt, are deposited. Marine animals play an important part in the formation of limestones and plants are important factors in the formation of peat and coal. The principal classes of clastic rocks are sandstones, conglomerates, shales and limestones.

**Sandstones** are more or less indurated sandy sediments. There are sandstones so friable that they are easily crumbled with the fingers and others, on the other hand, are so firm that they are extremely resistant and are important mountain makers. The constituent grains vary in size but are mostly rounded because their transportation by water has given them this shape. Furthermore, the grains are mostly composed of quartz, because this mineral is very resistant while the minerals that may have been associated with quartz in the parent rock have been worn away. The hardness of sandstone is mostly that of quartz, but the coherence is mainly due to the cements; a youthful sandstone may locally be cemented to a very hard rock while an old rock may be friable if there is little or no cement. The cements are mainly siliceous, calcareous and ferruginous. Siliceous cements make hard, durable sandstones which yield but slowly to weathering and erosion. Such sandstone makes many of the ridges in the Appalachian Ridge Belt, Fig. 58. Calcareous cements are relatively weak and in consequence many sandstones having this cement break down rather easily into deep soils, but some calcareous cements make rocks that are easily worked and, therefore, widely used as building stones. Ferruginous cements usually give firm sandstones with colors ranging from red, brown to bluish. When not white, the colors of sandstonse are mostly due either to the coating of the grains or to the cements. Sandstones vary in weight and are seldom as heavy as quartz because of their pore spaces. The sand grains do not ordinarily fit closely together so that these rocks are usually porous and often contain artesian well water.

**Chemical Composition.**—Fig. 31 shows the chemical composition of 253 sandstones, including many varieties. The high percentage of silica is at once evident, showing the high sand content. The alumina is mainly in the small amount of clay which nearly all sandstones carry. There are considerable amounts of lime and potash which is derived mainly from fragments of feldspars. Part of the iron and magnesia is due to the micas which are frequently found in sandstones and some of the lime, iron and silica represent the common cements.

While silica is the essential mineral of sandstone, clay is almost always present, especially in fine-grained sandstones, because the currents which can carry fine sand usually carry some clay; not infrequently an

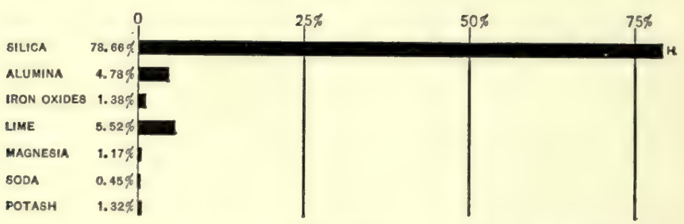


Fig. 31.—Composite analysis of 253 sandstones. (After H. N. Stokes, U. S. Geological Survey.)

apparently highly siliceous sandstone will weather to a loam instead of a sandy loam because of the clay in the sandstone. Mica is a common constituent, for while mica is a light, soft mineral, it endures transportation by currents and waves remarkably well. Such *micaceous sandstones* split easily since the mica flakes lie more or less parallel. *Arkose* is a sandstone which contains notable amounts of feldspar. The soils from arkose are naturally somewhat high in lime and potash, other things being equal.

**Conglomerates** are cemented gravels with the same cements as sandstone, Fig. 32. As the rounded grains of sandstone become larger the rock grades into a conglomerate. Conglomerates nearly always contain a considerable amount of sand but seldom much silt or clay since these materials are so light that currents able to carry gravel would sweep the finer materials away. The gravels are usually of some form of silica such as quartz, flint or chert but often there are rounded fragments of other rocks such as granite, quartzite or even limestone. Conglomerates are usually associated with sandstones since the same conditions favor the formation of both. When conglomerates break down into soils, they usually yield gravelly loams. **Breccia** is much like a conglomerate except that the fragments are angular instead of rounded. Some breccias are not due to stream action but are cemented fragments that have remained in place. Other breccias are water-deposited but the fragments have not been carried far enough to round them. There is considerable pore space in breccias because of the angularity of their fragments, with the frequent result that the ground water circulates freely and fills the interstices with other minerals. Important zinc breccias have been made in this way.

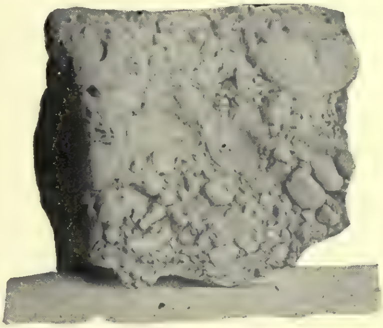

FIG. 32.—Conglomerate. (N. J. Geological Survey.)

**Shales** in typical form are indurated clays and hence they are often called "mud stones." The basic mineral is kaolin ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$). The term is a loose one since clays themselves are varied and the term shale usually pertains more to structure than to composition. Shales are deposited in relatively quiet water and often grade into sandstones or contain enough sand to be termed sandy shales. They are usually arranged in layers, sometimes so thin that they are called "paper shales." When they contain mica, as they frequently do, they split easily along their bedding (stratification) planes and are often improperly called slates. Flagstones are sandy shales that split into slabs of convenient thickness for paving.

Shales are commonly dark in color but many which contain some compounds of iron show red to brown colors. Some black shales are carbonaceous and, before the days of abundant petroleum, the distillation of oil from such shales was a considerable industry. Shales are extensively used in the manufacture of brick, tile and crockery. They break down readily into soils, especially when the bedding planes are numerous. As a rule the soils from shales are heavy loams, but sandy shales may yield sandy loams, and there are many gradations from clays and silt loams to sandy loams in soils derived from shales. Such soils are widespread and fairly productive.

**Chemical Composition.** Fig. 33 shows the composite composition of 78 shales, including all common varieties, and Fig. 34 shows for comparison the composition of kaolin the basic mineral of clays. The comparison of shales with sandstones shows a sharp decline in the amount of silica and an increase in the alumina. But on comparing


FIG. 33.—Composite analysis of 78 shales. (After Stokes, U. S. Geological Survey.)

these with corresponding compounds in kaolin we note that the shales contain more silica and less water and alumina than kaolin. This indicates that the shales contain many impurities. The high silica indicates a large amount of fine sand and this sand content explains the fact that many apparently heavy shales yield surprisingly light loamy soils. The alkalies and iron oxides are in part due to undecomposed fragments of feldspars and ferro-magnesian minerals.

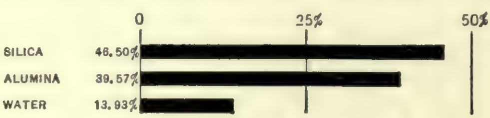


FIG. 34.—Diagram showing the composition of pure kaolinite. (After Clarke, U. S. Geological Survey.)

**Limestone** is an important and rather widely distributed rock, the basic mineral of which is calcite ($CaCO_3$). It is widely used as the source of lime, which is derived from limestone by roasting according to the following reaction:

| Calcite | yields | quick-lime | and | carbon dioxide |
|---|---|---|---|---|
| $CaCO_3$ | = | $CaO$ | + | $CO_2$ |

Limestone and other calcareous rocks will effervesce upon the application of cold dilute acids and this test offers an easy method of identification when the observer is in doubt. There are all gradations from soft, chalky friable limestones to firm dense rock that breaks with a conchoidal fracture. The colors are commonly white and gray but with the addition of carbonaceous matter the color darkens and many limestones are black; these, however, will usually burn to white lime when the carbonaceous matter is burned out. Less common are limestones of brownish and reddish tints which are due to varying amounts of iron oxides.

By far the most important limestones are of combined organic and marine origin as is evidenced by the marine fossils often found in limestone, Fig. 35. On the other hand there are many limestones unquestionably formed in the ocean that are destitute of fossils because the materials of limestone are soluble and may be dissolved and redeposited many times over and the fossils thus obliterated. Corals are important limestone makers and good illustrations are found around modern coral reefs, where the waves break the coral skeletons into coral sand slight portions of which are dissolved by the sea water and deposited between the grains, thus making a coralline limestone. Such limestones, much changed by solution and redeposition, but still preserving their fossil coral structure, are found very extensively in certain formations. Not only corals but practically all the marine animals which have calcareous skeletons contribute to the formation of limestones. Mollusks (two-shelled animals) and tiny one-shelled creatures (foraminifera) have contributed their skeletons to limestone formations. **Coquina,** Fig. 255, a very recent limestone, consists simply of shells cemented by lime carbonate and is doubtless an example of the first stages in many limestones.

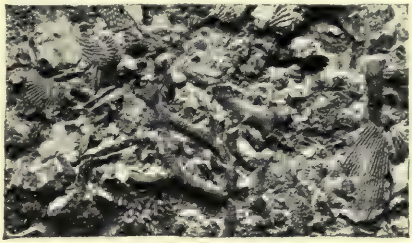

Fig. 35.—A fossilliferous limestone. The lowly animal forms have been long extinct. (U. S. Geological Survey.)

Very extensive beds of limestone originated as calcareous ooze in rather quiet water, either deep or moderately shallow. When such deposits are accumulated not far from shores, they are likely to contain considerable sediment as silt or clay or sand. Hence we have the frequent gradations from limestone to shales or to sandy shales or even to sandstones, Fig. 30. Non-marine limestones are not of wide extent although they may form thick masses locally. They may be found around many calcareous springs, where they sometimes form the attractive banded *travertine.* Lime carbonate may on a small scale be precipitated in closed bays or even in the open ocean but it is doubtful if much limestone has accumulated by precipitation.

**Varieties.**—The frequent gradations of limestone to shale and to sandstones have been noted before. As a matter of fact, practically no limestone in nature is free from varying amounts of clay so that limestone soils produced by the decomposition of limestone are always somewhat clayey. *Chalk* is a crumbly limestone composed largely of microscopic shells and their fragments. *Dolomitic limestone* is a widespread limestone which contains considerable amounts of magnesium carbonate ($MgCO_3$). *Cherty* or flinty limestone are also very common and give rise to many types of stony and loamy soils. The chert may be fine grained and scattered through the rock or it often occurs in lenses or strata, Fig. 36. Some of the chert was doubtless deposited with the limestone-forming materials, but it is believed that much has been deposited by the ground water after the rock was formed. Phosphatic limestones have much agricultural interest since they contain variable amounts of lime phosphate.

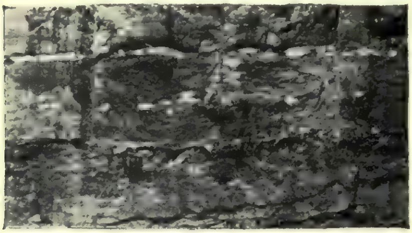

Fig. 36.—Cherty limestone. The chert occurs in layers. (Mo. Geological Survey.)

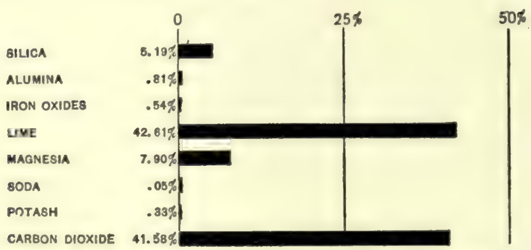


Fig. 37.—Composite analysis of 345 limestones. (After H. N. Stokes, U. S. Geological Survey.)

**Chemical Composition.**—Fig. 37 shows the composite analysis of 345 limestones. One at once notes the high content of lime and carbon dioxide which constitute the basic mineral calcite ($CaCO_3$). The considerable amount of magnesia represents the magnesian (dolomitic) limestones, which are somewhat widespread. The alumina and part of the silica constitute the clay which is found in nearly all limestones. The iron content seems low when it is remembered that many limestone soils are of reddish tints, but as we shall see later, the color of soils and many fine-grained rocks is largely conditioned by the fineness of grain of the coloring materials.

## Structure of Sedimentary Rocks

An exposure of sandstone or shale will often suggest the origin. Layers of sandstone and shale will often alternate much as may be seen in the deposits of a roadside stream. Such an arrangement of layers is termed *stratification* and the arrangement is due to the sorting action of water or sometimes of wind (see Fig. 30). Rapidly moving water can carry coarser materials than slow currents, a fact that will be more fully discussed later. If we have, for example, a layer of conglomerate overlying a layer of sandstone which, in turn, is underlain by shale, it can be safely stated that the conglomerate was deposited by rushing water, the sandstone by swift currents and the shale by relatively quiet water.

Then other characteristics besides size of materials may give a stratified structure; differences in color or weight may be marked in different layers. Some sandstones and shales show bands of purple, red, dark and white colors so that local names such as " painted rock " are applied. A single layer of similar material is often termed a *stratum* and very thin layers are termed *laminæ.* A group of strata is often called a *formation.* The planes of division between strata are termed *bedding planes.*

**Monoclinal Structure.**—Another structure, especially well shown in some areas of sedimentary rocks, is where the rocks dip only in one direction and hence the structure is appropriately termed monoclinal (one-dip) structure. Such structure is to be distinguished from horizontal rocks on the one hand, and on the other hand from formations which are bent so as to dip in two directions as shown in Fig. 49.

Over large areas where there has been no folding, the beds often dip gently in one direction and so have monoclinal structure. Such structure is especially characteristic of the Great Coastal Plain which, beginning at New York, sweeps southward and westward to Mexico and includes millions of acres. The gentle dips of sedimentary beds of the

Coastal Plain is due not to folding but to their having been laid down in a sea and later elevated and tilted.

The monoclinal structure of a coastal plain is shown in Fig. 251, which represents a portion of southeastern Alabama and, as this will serve as a general illustration of this structure, it will be considered in some detail. First there was an old land, the Piedmont, which, in this locality, was to the northward. As the Piedmont was eroded the resulting sediments were deposited in overlying strata, the oldest at the bottom. Later the ocean bed formed by these strata was elevated and formed the present Coastal Plain. The formations dip to the southward and, in going from north to south over the Coastal Plain, one would cross successively younger beds, first the Cretaceous and then the younger Eocene outcrops. Some strata are strong and others weak, so that in places there are corresponding ridges and lowlands, but in general the Coastal Plain, as the name implies, is somewhat level or rolling. Monoclinal structure is shown on a large scale in some old rocks. For example the rocks in New York and Northern Pennsylvania dip gently southward. The strata leading from the eastern base of the Rocky Mountains dip away under the Great Plains for hundreds of miles while near the mountains they are sharply uptilted, giving the ridges so well shown in the Garden of the Gods. Some of these strata carry water and furnish the main source of artesian water in the Great Plains, Fig. 108.

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## METAMORPHIC ROCKS

These are rocks that have been greatly changed from their original condition. Igneous and sedimentary rocks may be changed to this class or indeed one metamorphic rock may be changed into another. The process (*metamorphism*) may be slight as when a shale is hardened and becomes a shaly slate or, as is often the case, the metamorphism may be so complete that one cannot tell from what a metamorphi rock was derived. In general the process of metamorphism strengthen rather than weakens rocks but this does not always hold; limestone for example, is usually a weaker rock than marble into which limestone fre quently changes and slate is almost always harder than its parent rock, shale.

**Changes Produced by Metamorphism.**—Metamorphism may result in changes that are mainly *physical*, as when a pure limestone is changed to a marble of practically the same composition Frequently there is *chemical change*, as when orthoclase feldspar is changed by addition of water to muscovite mica, according to the equation on page 49. Very often there are *mineralogical changes* by which different minerals are developed from minerals al eady in the rock. An interesting example of this is found in the metamorphism of impure limestones, which often contain free quartz, iron oxides, clay, magnesia and, of course, calcite. Under metamorphism these compounds often unite to form a great variety of minerals among which are mica, feldspars and garnets.

## Agents of Metamorphism

The principal agents of metamorphism are heat and pressure and to these are often added the effects of hot water and gases, especially steam. It is obvious that such enormous temperatures and forces cannot be reproduced and studied in laboratory experiments nor can they be studied in action. The study of metamorphism and its agents is, therefore, particularly difficult; much more is known of the effects of metamorphism than of the agents that produce it.

**Heat,** causing metamorphism, may be due to at least three factors: (1) At the depth of several miles the weight of the overlying rocks is enormous. The deep-lying rocks are subjected to great compression which produces heat for the same reason that pounding a piece of metal will make it hot. (2) Rocks in some places have been closely folded to great depths and such folding, though it was very slow, has produced heat much as the rapid bending of a wire will heat it. (3) Furthermore it is obvious that highly heated lavas under some conditions will provide heat for metamorphism.

The influence of heat is readily understood from common observation. Heat hardens and bakes rocks, drives off volatile substances and also raises the temperature of water and gases so that they become more effective agents of metamorphism. Moreover the expansion and shrinkage often associated with heating and cooling break up rock and so facilitate the easy penetration of hot water and gases. Then great heat tends to make rocks somewhat plastic, a condition that favors metamorphism. Many rocks, especially shales near large masses of hot lava, are baked to a dense glassy substance termed hornfels; clays are baked to a porcelain-like substance and sandstone to a glassy, enamel-like rock. A simple case is seen when bituminous coal is invaded by hot lava with the result that the coal near the lava is changed to anthracite or coke by the expulsion of volatile substances from the bituminous coal, Fig. 38.

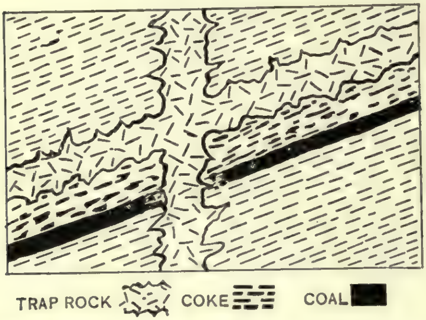


Fig. 38.—Diagram to illustrate the change from bituminous coal to anthracite by an intrusion of lava. (After Shaler and Woodworth, U. S. Geological Survey.)

**Pressure.**—The great pressure caused by the weight of hundreds of feet of overlying rocks has been noted. Most of the well-marked metamorphism due to pressure, however, is caused by the folding of rocks. Not only does folding produce great heat and pressure but it tends to shatter the rocks and thus provide easy channels for gases and hot fluids which are in themselves important factors. An effect of folding is well illustrated in Pennsylvania, where one may follow a horizontal bed of bituminous coal to where the beds are folded and the coal changes to anthracite as a result of the folding, Fig. 39. It is largely for this reason that many metamorphic rocks of economic value such as marble, slate and anthracite are found for the most part in regions of folded rocks.

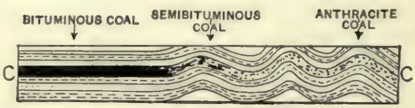


Fig. 39.—Diagram to illustrate the metamorphism of bituminous coal to anthracite because of folding. (*C* indicates a coal bed.)

**Gases and fluids** are factors in metamorphism that produce great complexity. Water is by far the most abundant of all fluids and an enormous amount is contained in rocks. Other gases such as fluorine, chlorine and carbon dioxide are present in some rocks. The water may be in chemical combination in minerals or in some way not well understood it may be "occluded" or hidden in the rocks. Rocks will melt much more easily in moist heat than in dry heat, some requiring only about one-third the heat for melting in moist heat as compared with dry heat. Water is an efficient solvent and its solvent power is greatly increased when the water is at the high temperatures encountered in deeply buried rocks. Moreover such water readily enters into various combinations. The micas, for example, are hydrated minerals very common in metamorphic rocks. One way by which they can be formed is shown by the following equation:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Orthoclase (potash feldspar). | added to | water | yields | Muscovite (potash mica) | and | Potassium silicate | and | Quartz |
| $3KAlSi_3O_8$ | + | $H_2O$ | = | $KH_2Al_3Si_3O_{12}$ | + | $K_2SiO_3$ | + | $5SiO_2$ |

The potassium silicate is soluble in hot water and may enter into other combinations. Another common hydrated mineral often found in metamorphic rocks is talc. Furthermore circulating hot waters may carry minerals in solution and redeposit them in the interstices of rocks as in quartzites or it may dissolve and recrystallize the minerals of a rock, a process often prominent in the formation of marbles.

FIG. 40.—Foliated gneiss produced by intense folding. N. C. (U. S. Geological Survey.)

**Slaty Cleavage and Schistosity.** — Many metamorphic rocks are slightly banded and split easily in one or more directions. Thus there is slaty cleavage in rocks that are not otherwise much changed. This cleavage is due largely to the development of minute flakes of mica along certain planes whereby the rock splits more easily. Slaty cleavage is caused by moderate metamorphism. When the metamorphism is more vigorous there is a development of many new minerals which are roughly parallel with each other and often arranged in bands, a structure termed *schistosity*, and the rock is said to be *foliated*. There is usually easy splitting along these bands, Fig. 40.

One way by which slaty cleavage and schistosity may be developed is illustrated in Fig. 41. Suppose, for example, we have granite (*A*), the minerals of which have no definite directions, and that this rock is subjected to pressure in the direction indicated by the arrow. As new minerals are formed they tend to grow along directions where the pressure is less, that is, approximately at right angles to the pressure, and so develop slaty cleavage or foliation.

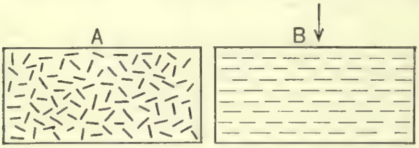

FIG. 41.—Diagram to illustrate the development of schistocity by pressure.

**Complexity of Metamorphism.**—It will be readily apparent that it is practically impossible to separate the effects of the different agents of metamorphism in most field studies. While for ease of comparison they have been considered separately, it should be remembered that in nature they act jointly and so intricately that it is extremely difficult to study their separate effects. Pressure tends to produce heat, and heat, by expanding the rocks, produces pressure. Both heat and pressure facilitate the work of liquids and gases.

## Contact and Regional Metamorphism

It is convenient to consider metamorphism under two phases. When a mass of molten material comes into contact with other rocks there are likely to be changes at or near the contact and such metamorphism is accordingly termed contact or local metamorphism. The region affected is relatively small. Regional metamorphism occurs on a larger scale and is due largely to pressure produced by folding. Since this type of pressure does not operate on a small scale, the metamorphism affects large areas. Great areas in the Appalachians and in the Rockies are underlain by rocks produced by regional metamorphism. It should be kept in mind that these two phases are not distinct and that each involves many of the factors operating with the other.

**Contact metamorphism** naturally involves the intrusive molten rock and also the rock into which the intrusive lava is forced. The larger the mass of molten rock the greater will be the metamorphism, since there is more heat to be radiated from the larger mass. Furthermore, if the molten mass is flowing instead of stagnant there will be greater heat effects. Other things being equal, deeply buried molten rocks are likely to be especially effective since the heat escapes so slowly that its effect is prolonged and, moreover, the associated hot gases and vapors are in effect for longer periods.

An illustration of contact metamorphism is shown in Fig. 42. Here the molten rock (diorite) has been forced through a great thickness of conglomerates, sandstones and clays. The heat and vapors of the intruded mass have formed a zone of metamorphosed rock in places over a mile wide. The metamorphism decreases from the central core until the metamorphic rocks merge into the stratified sedimentaries. Fig. 43 shows the metamorphism of a limestone by a large m ss of lava. The same features are illustrated in

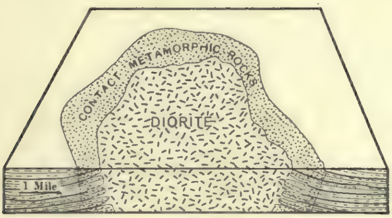


FIG. 42.

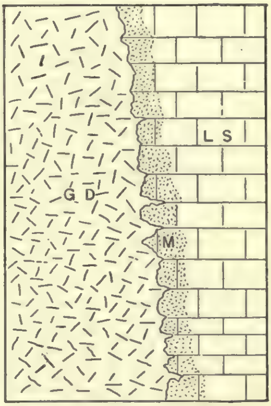


FIG. 43.

FIG. 42.—To illustrate contact metamorphism. (Data from U. S. Geological Survey.)

FIG. 43.—Limestone (*LS*) metamorphosed by an intrusion of lava (*GD*). The diagram shows the lava on the left (*GD*) which has made a zone (*M*) of changed limestone. The illustration shows the small area of this zone where portions of the limestone have been changed to a dark mass of minerals. (Photo by Paige, U. S. Geological Survey.)

Fig. 18, where a dike in Pennsylvania has penetrated shales and shaly sandstones. On each side of the old dike the reddish shales have been baked to a bluish color and have been made somewhat hard and slaty. The soils from this metamorphosed zone are bluish in color and contain fragments of rock in contrast to the reddish soils from the unaffected sandstones.

**Regional metamorphism** is associated with the great pressures involved in extensive earth movements, such as folding and warping of the earth's crust. Rocks are often so completely changed that it is extremely difficult, if not impossible, to ascertain their original condition. Often when a mass of stratified rock has been subjected to metamorphism, it is found that the rocks more susceptible to these processes will become metamorphosed while others are apparently but little affected.

Some of these features are illustrated in Fig. 44, which shows a section of closely folded rocks in the Green Mountains of Massachusetts. It is uncertain as to the former condition of the gneiss (*G*) for the rock has been so thoroughly changed. The Vermont formation (*V*) shows interesting transformations. In places it is a metamorphic conglomerate, the crushed and broken pebbles of which bear evidence to the great stresses to which the rock has been subjected. The limestones (*L*) have, for the most part, been changed to marble which often contains mica. A careful study of these formations shows that they have been derived from sedimentary rocks. As proof a few fossils have been found and, moreover, it has been possible in places to trace a given formation from metamorphosed rock to limestones, sandstones or shales.


FIG. 44.—Section of metamorphosed rocks in the Green Mountains, Mass. (U. S. Geological Survey.)

## Kinds of Metamorphic Rocks

Metamorphic rocks are commonly divided for description into two classes, the *foliated* (banded) and the *non-foliated.* The foliated rocks include gneiss, schist and perhaps slate, although the banding in slates is obscure. The non-foliated rocks include marble and quartzite.

**Gneiss** (pronounced *nice*). These rocks are coarsely banded with the bands commonly of different minerals, Fig. 40. Very often the light-colored bands contain quartz and feldspar, and the dark-colored bands, the ferro-magnesian minerals. Such an appearance has given rise to the common name, " banded granite." There is considerable variation in composition although most of the gneisses correspond to the acid igneous rocks of which granite and syenite are examples. They are usually somewhat hard, durable rocks but their easy splitting renders them unfit for building purposes where they must sustain considerable weight. They are almost invariably found in regions of regional metamorphism where the rocks have been subjected to great pressure and folding. Sandstones, some shales, granites and yet other rocks have been traced into regions where they have been changed to gneisses. According to the predominating minerals there are biotite gneiss, hornblende gneiss, etc. The structure of gneisses causes them to break down into soil rather readily and they are important soil formers in the Piedmont Plateau of the eastern United States.

**Schists** are finely foliated rocks, usually dark colored and in general they contain less quartz and feldspar and are, therefore, more basic than gneisses. Shales, diorites and schists commonly have much the same composition, and in general, schists correspond in composition to the basic igneous rocks. Both local and regional metamorphism produce schists. They, accordingly, have a wide distribution and vary greatly in composition. Mica is a very common mineral in schists, but a great variety of minerals, including garnet, quartz, feldspars, hornblende, talc and many other minerals are found in these rocks. As in gneisses the predominating mineral gives its name to the schist, and as the feldspar and quartz increase and the banding becomes coarser the schists grade into gneisses.

Schists are seldom hard or durable. Their easy cleavage, softness and weakness prevent their use for road metals, building and for other structural purposes. Locally they yield garnets, corundum and other minerals. Owing to their weakness, schists readily break up into smaller pieces but do not so readily decompose into soils and the prevailing mica often causes the soils to be highly micaceous. The general lack of feldspars causes soils derived from schists to be somewhat poor in lime and potash. Since they are relatively weak rocks, schists usually wear down to lowlands while adjacent gneisses commonly make highlands.

**Slates** have the well-known quality of easy splitting. This, as has been noted, is due to the growth of very small minerals, mostly mica, which lie parallel to each other and thus facilitate splitting and give the dull silvery sheen to be seen on smooth slate surfaces. In composition and often in appearance, slates often resemble shales and, in fact, easy splitting shales are often incorrectly termed slates; the geological usage is to restrict the term to metamorphosed rocks only. They are in most cases the product of regional metamorphism so that the productive slate belts of Vermont, Pennsylvania and Virginia lie in the folded rocks of the Appalachians and the slate fields in Wales lie in regions of intensely folded rocks.

Fig. 45.—Slate developed from shale by metamorphism. (Dale, U. S. Geological Survey).

Slates are typically changed from shales and the lines of cleavage developed in slate may or may not coincide with the bedding planes of the shale. It will be clear from Fig. 41 that these planes will not coincide unless the pressures are about at right angles to the bedding planes. Fig. 45 shows old bedding planes folded downward while the main slaty cleavage planes are straight and do not at all correspond to the bedding planes. In some slates the old bedding planes are now represented by dark bands or " ribbons."

The colors range from blues, reds, brown, purple, black to gray. The hardness and easy cleavage make them well adapted for roofing. As a rule slates break easily into thin pieces under weathering but their further change is somewhat slow, so that soils derived from slate usually contain many fragments, and slates, therefore, commonly yield slate loams. Such soils often extend in long narrow belts which follow the slate outcrops.

**Quartzite** is a metamorphosed sandstone or less frequently a metamorphosed conglomerate. When the grains of a sandstone are so thoroughly cemented by silica that the whole rock is a solid mass the rock is a quartzite. This cementation may and often does occur as a result of local and regional metamorphism, but it also occurs in recent undisturbed sand and gravel. Therefore quartzite, unlike other metamorphic rocks, does not require earth movements for its formation, but is to be explained by water deposition of silica in the interstices of sandstones and conglomerates. The sand grains are not ordinarily distinct to the unaided eye, but the microscope shows the original sand grains surrounded by deposits of silica which binds them into an exceedingly hard rock, as is shown in Fig. 46. Quartzite ordinarily breaks with a conchoidal fracture and is usually so firmly cemented that the rock will break *across* the original sand grains rather than around them. There is naturally no sharp distinction between sandstone and quartzite and intermediate rocks are often termed " quartzitic sandstones " or " quartzitic conglomerates." On the other hand, quartzites grade into gneisses or schists when they have been subjected to pressure

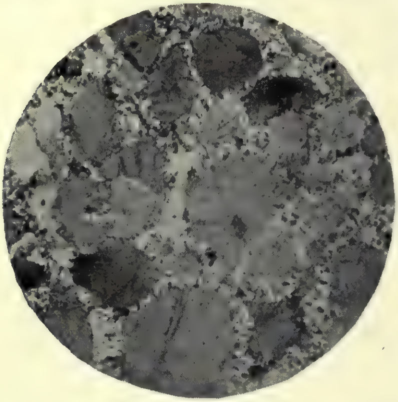

FIG. 46.—Quartzite. The grains (darker masses) have been cemented by silica. Microphotograph, much enlarged. (Maryland Geological Survey.)

sufficient to produce schistosity and also when there are sufficient materials for the development of feldspars, micas and other metamorphic minerals.

Quartzites have a peculiar glazed or glassy luster and are commonly gray or white in color although small amounts of iron oxides will impart reddish or brownish tints. Their extreme hardness prevents much use of the rock in structural work because of the difficulty in working it. Naturally quartzite breaks up very slowly under the attack of the weather. Typically it makes high, rugged country with but few areas of arable soils.

**Marble.**—This well-known rock results from the metamorphism of limestone or dolomitic limestone. It may result from either local or

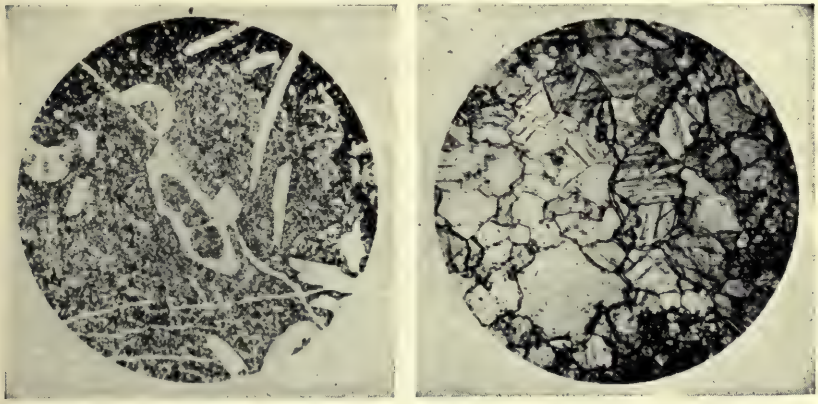

FIG. 47.—The limestone on the left has been changed to the marble on the right. Microphotograph. (U. S. Geological Survey.)

regional metamorphism and in the formation of marble water is an important factor, for it dissolves and recrystallizes the rock. For example, Fig. 47 shows a somewhat impure limestone with an irregular structure and the same limestone is seen changed to marble. The limestone has been dissolved and recrystallized into the large grains of the marble. The great pressure to which many marbles have been subjected has seldom produced the schistosity in them that is so well seen in gneisses and schists and this absence is probably to be explained by the fact that calcite and dolomite, the essential minerals, easily dissolve and recrystallize under pressure.

Pure limestone will change into a pure marble, but impure limestones afford materials for many metamorphic minerals and change into complex metamorphic rocks. The hardness of pure marble is that of calcite. Marble is used for building and decorative purposes because of its easy working, strength and pleasing appearance. Inferior marbles are sometimes burned for lime. As a trade name marble includes all calcareous rocks which will take a pleasing polish and are of commercial value and, indeed, there is no sharp division between marble and limestone. As a soil builder, marble behaves essentially as limestone but the areas are small and unimportant.

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## STRUCTURES COMMON TO ALL ROCKS

Nearly all consolidated rocks and even many clays are intersected by crevices or **joints** which are usually more or less perpendicular to the surface, Fig. 48; to a less extent, joints are found extending parallel to

FIG. 48.—Vertical and horizontal joints in granite, Conn. (U. S. Geological Survey.)

the surface. Joints are often roughly parallel to each other and so form **joint systems.** Moreover two or more joint systems often intersect at various angles, thus dividing the rocks into rough blocks and often presenting a curious effect of masonry. Bituminous coal is frequently intricately jointed and so breaks readily into small blocks, and quarrying of dimension stone is greatly facilitated by joints because blocks can thereby be easily taken out. From another point of view, jointing is very important in allowing the entrance of weathering agents whereby the rocks are broken up and ultimately changed to soils.

## Structures Due to Folding

While many rocks appear to be horizontal in ordinary sections, yet observation shows that many rocks are arranged in *folds* or wrinkles, either large or small. These folds in part explain why it is a common experience in nearly all mining and well drilling that certain strata lie at different depths—nearer the surface in the upfolds and deeper in the downfolds.

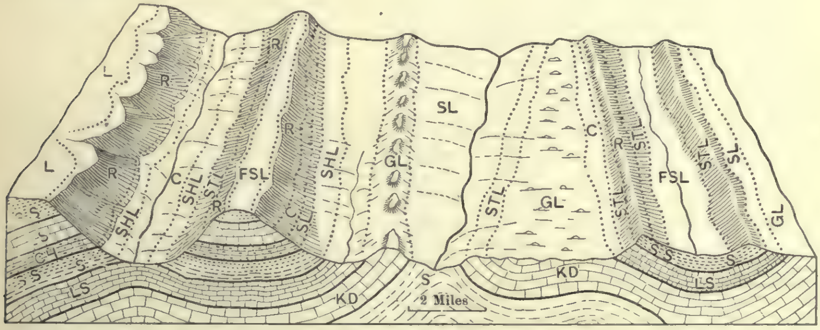


**Fig. 49.—Generalized diagram showing structure, topography and soils of folded rocks in northern Georgia.**

*Rocks:* (*SS*), sandstone; (*LS*), limestone; (*CH*), cherty limestone; (*S*), shale; (*KD*), Knox dolomite, a notable soil making formation here. *Soils:* (*L*), loam; (*STL*), stony loam; (*GL*), gravelly loam; (*SHL*), shale loam; (*C*), clay; (*SL*), silt loam; (*CL*), clay loam; (*FSL*), fine sandy loam; (*R*), stony soils. (U. S. Geological Survey; U. S. Bureau of Soils.)

It will be seen from Fig. 49 that folding has two important effects; it brings different rocks to the surface and also repeatedly brings up the same formation. It will also be noted that folded rocks outcrop in more or less parallel belts. These belts in weathering to soils give more or less parallel soil belts which are shown in the same diagram. A study of these soils shows that the soil belts do not always correspond to the different geological formations exposed, since some adjoining

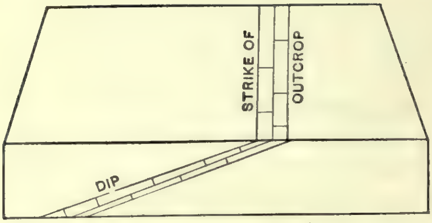


FIG. 50.—To illustrate dip, strike and outcrop.

formations do not differ materially except that they contain different fossils and so are classed as different formations. On the other hand, a single formation may yield different soil types at different places because of surface differences of drainage or erosion or because of some differences in composition. Thus it is not safe to assume that soils in various localities are the same because they are derived from the same formation. However, the soil belts from a single formation are usually somewhat similar.

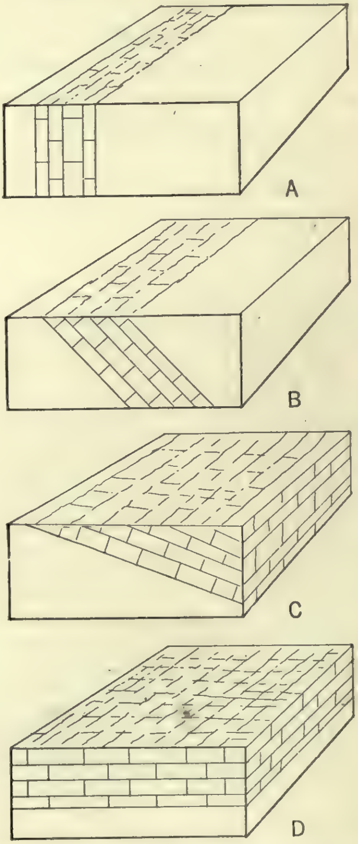


FIG. 51.—Diagram illustrating the changing width of outcrop due to variations in dip.

**Dip and Strike.**—At this point it will be useful to introduce terms used in describing rocks that are not horizontal. The angle that a stratum or formation makes with the horizon is termed the *dip*. If a stratum is vertical the dip, of course, is 90° and from this the dip or a stratum may vary to a horizontal position when the dip is zero. The direction of the dip is also given; for example, a stratum may dip 15° northwest. *Strike* is the imaginary line where a dipping stratum intersects the plane of the horizon, Fig. 50; it is perpendicular to the dip. It will further be evident that dip is expressed in degrees and direction while strike is expressed in direction. For example, a stratum may dip 20° west and strike north-south. It is important to note the relation between dip and width of outcrop. For example, in Fig. 51 consider a stratum with uniform thickness to be dipping at various angles. When the stratum is vertical (*A*) the outcrop is as wide as the stratum is thick and in this position the outcrop is narrowest. As the dip decreases (*B* and *C*) the width of the outcrop increases until the maximum width of outcrop (*D*) occurs when the stratum is horizontal. With this in mind it is clear how a given dipping stratum, say of limestone, may in one place yield a soil belt three miles wide while in another place the width may be more or less according to the dip.

FIG. 52.—Anticline of sandstone, Md. (U. S. Geological Survey.)

**Anticline and Syncline.**—An *anticline* is an arch-like upward fold, Fig. 52, with the rocks dipping *down* on either side from the center. A *syncline* is the reverse of the anticline, being a trough-like fold with the rocks dipping *inward* towards the center, Fig. 53. Anticlines and synclines usually occur together. Sometimes the folding is open and again the folds are closely folded and very complex.

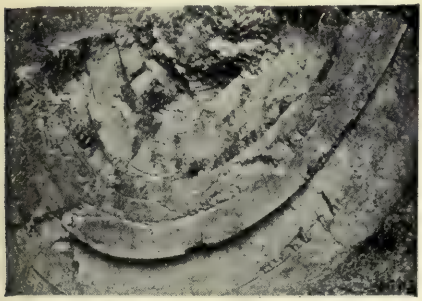

FIG. 53.—Syncline of shale, Pa. (U. S. Geological Survey.)

An important belt of folded rocks is found in the Eastern United States, Fig. 54, which practically extends from Nova Scotia into Alabama. Especially notable in this folded belt is a wide, rather level floored valley which extends from New Jersey into Alabama under various local names such as the Kittatinny Valley in New Jersey, the Lebanon and Cumberland Valleys in Pennsylvania, the Shenandoah Valley in Virginia and the Tennessee Valley farther south. Folding has upraised a belt of limestone and shales which underlie the valley and yield the well-known fertile soils. A section across this valley in Pennsylvania appears in Fig. 55. The limestones and shales yield respectively the Hagerstown and Berks soil series. On the east is South Mountain, a group of hills carved from sandstone and quartzite, and on the west are the ridges of the Ridge Belt. Folding of all degrees is found in the Cordilleran Mountains of the West. The Alps are also notable examples of folding.


FIG. 54.—A part of the Appalachian Ridge Belt. (U. S. Geological Survey.)

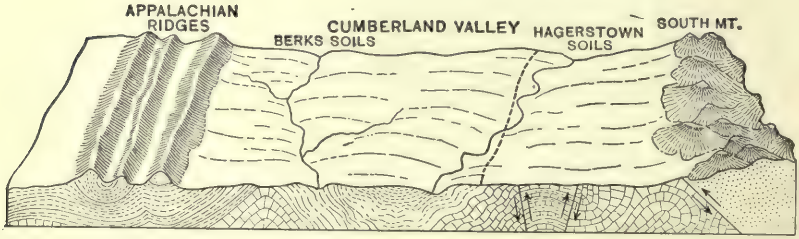


FIG. 55.—Diagram to show rock structure and topography of the Cumberland Valley and South Mt. in Pennsylvania. (Data after U. S. Geological Survey and U. S. Bureau of Soils.)

## Topography Produced by Folding

Not only must the residual soil belts produced by folding be considered, but also the topography, for topography is perhaps as important a soil factor as the parent rocks. When strong and weak rocks are exposed to erosion under the same conditions, the weak rocks will wear faster and produce a lower area than the area underlain by strong rocks. In other words, the strong rocks make the higher and the weak rocks the lower, country.

It is somewhat natural to think of anticlines as ridges and synclines as valleys and such is often the case, especially with rocks that were recently and rapidly folded. But, on the other hand, where the folding was ancient and the rocks have been long exposed to erosion as in the Appalachian Mountains, the reverse is often the case. A somewhat ideal case is illustrated in Fig. 56, where a homogeneous rock such as, for example, a granite, has been folded. It will readily be seen that the rocks in the upper parts of anticlines are stretched and tend to be shattered and weakened. On the other hand, the rocks in the synclines, especially in the lower parts, are somewhat compressed and less weakened. As a result the anticlines wear away faster and become valleys and the synclines, being relatively less eroded, are left as ridges. The development of anticlines into valleys and synclines into mountains finds an interesting illustration in the anthracite coal field of Pennsylvania. The coal overlying the anticlines has often been removed by erosion while the coal in the synclines has often been preserved.

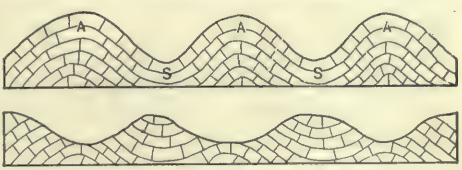


FIG. 56.—Diagram to illustrate the evolution of valleys on anticlines.

As a matter of fact, such simple conditions are rarely found. The most characteristic topography resulting from folding is found in regions of folded sedimentary rocks. Here the rocks of various strengths are exposed with the result that the weaker rocks are worn to valleys, while the relatively strong rocks form ridges as shown in Fig. 57. The upturned strata form rather straight, even crested ridges which when followed for some distance, usually curve and finally disappear as the rock may become relatively weak. Between the ridges are rather narrow valleys in which most of the arable lands and population are located.

Blue Mountain in Pennsylvania is one of these ridges, Fig. 58; it is due to resistant sandstone and extends with fairly even crest for scores of miles. Thus the streams and their valleys usually map the weak rocks

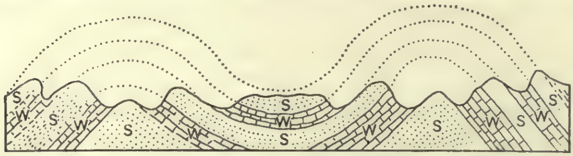


FIG. 57.—Diagram to illustrate the development of ridges and valleys on folded rocks. The strong rocks (*S*) make the ridges and the weak rocks (*W*), the valleys. The dotted lines indicate the eroded strata.

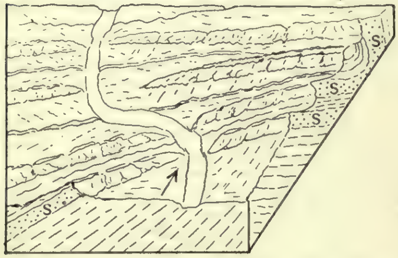


FIG. 58.—Ridges caused by folding. Distant view above; the first ridge is Blue Mountain. The Diagram below shows four ridges made by sandstones (*S*) which have been upturned by folding. The arrow shows the position of the camera. The two ridges in the foreground of the diagram are those shown in the photograph. Penna.

and the ridges map the strong rocks, both valleys and ridges being more or less parallel. So characteristic is this parallel arrangement of streams in folded rocks that such structure can sometimes be detected from ordinary maps.

The "Blue Grass" Basins of Kentucky and Tennessee are examples on a large scale of eroded anticlines, Fig. 59. An extensive but low anticline was uplifted and its upper portion has been eroded. Hundreds of feet of overlying rock have been removed so that the underlying limestone in the anticline has been exposed and the limestone now affords the famous productive soil of these regions. The "Highland Rim" which surrounds the basin has not been eroded so fast. Its sandstones and shales afford less productive soils and, moreover, the surface has been eroded to a hilly topography.

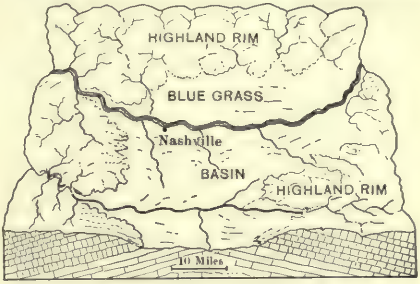

FIG. 59.—Diagram of the Blue Grass and Highland Rim regions of Tennessee.

## Faults

A close examination in almost any quarry will usually show small cracks along which the rocks have slipped, Fig. 60. Such breaks where rocks have slipped so that formerly continuous strata no longer match are termed *faults*. It should be noted that not all cracks are faults; only when movement has occurred along the breaks is the term applied. Faults of various magnitudes are much more common than might be supposed since many faults are concealed and many others are hard to detect. Some terms are convenient in the description of faults. Fig. 61 shows a fault in which the strata ($S$) on the right have been elevated relative to those on the left and consequently the right side is termed the *upthrow side* and the left, the *downthrow side*. These terms are merely relative and do not imply that the rocks on the right

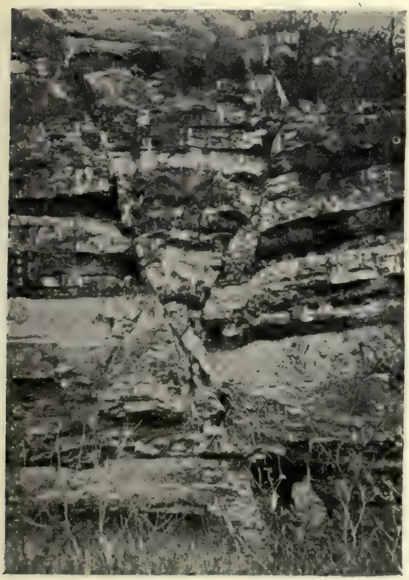

FIG. 60.—Small faults, Texas; the strata do not match. (U. S. Geological Survey.)

were actually pushed up or the rocks on the left depressed; the arrows show the relative movements.

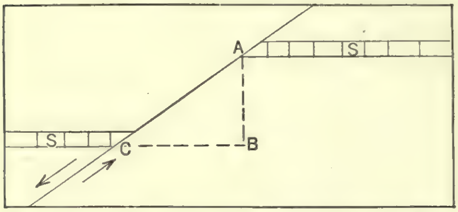

FIG. 61.—Diagram to illustrate a fault.

Angle $BAC$ is termed the *hade* of the fault. The vertical displacement $AB$ is termed the *throw*, the horizontal displacement $BC$, the *heave*, while the movement along the fault $AC$ is the *displacement*.

## Effects of Faulting

Faults of much magnitude rarely occur singly, but usually in a group of more or less parallel faults, the *fault zone.* Faults are naturally more numerous in folded rocks where the rocks have been stressed and broken by the enormous strains to which they were subjected. From an agricultural point of view, faults are interesting both from their direct and their indirect effects on soils. The **direct effect** is seen when faulting brings up on the upthrow side a rock which yields soils different from what they would otherwise have been. The **indirect effects** are due to the influence of faulting on topography. Soils on the upthrow side are often higher, and t herefore exposed to greater erosion; they are likely to be thinner and often more stony as a result of the upthrow. Soils on the downthrow side are likely to be lower, less actively eroded and to have less active drainage as results of the downthrow.

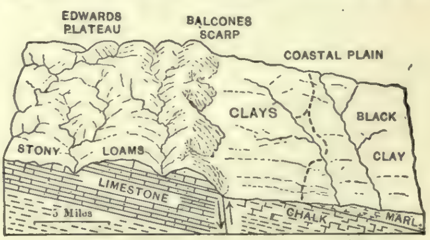

FIG. 62.—Diagram showing an effect of faulting on soils. The limestone on the left has been brought up by faulting and yields stony soils, Texas. (Data after Hill, U. S. Geological Survey.)

Both of these effects are seen in central Texas, Fig. 62. West of Austin is a series of faults, a fault zone, running in a north-south direction with the upthrow side on the west. Between the upthrow and downthrow sides is a steep, eroded slope (escarpment) known locally as "The Balcones." The lower, rolling country is a part of the Coastal Plain; the high country is known locally as the "mountains" or the Edwards Plateau. This plateau because of its height has been eroded so that the topography is for the most part very hilly and, as a result, much of the soil has been washed away, leaving the remaining soils thin. The underlying rock is hard flinty limestone. As a whole the soils are stony loams. The lower, level Coastal Plain is much less eroded. The black clay soils are derived largely from a marly clay. The clay soils are largely derived from a chalky limestone.

It is natural to think of the upthrow side as forming a steep slope (escarpment) near the fault and when this occurs, the slope is termed a *fault scarp*. Such a fault scarp extending for miles is found in central Texas, Fig. 62. A recent fault scarp is shown in Fig. 63. A fault scarp may be made by an upthrow which elevates one side but such a scarp is likely to be worn down and obliterated by erosion in a comparatively short time as time is reckoned in geology. On the other hand, if the upthrow side is composed of relatively resistant rock the fault scarp may persist for a long time.

Fig. 63.—Fault scarp in Arizona. Land waste has accumulated at the base of the scarp and conceals the lower part. The diagram shows the structure. (Ransome, U. S. Geological Survey.)

The eastern slopes of the Sierras consist of a series of great fault scarps with throws of hundreds of feet. Fresh fault scarps are found in New Mexico and Arizona which extend practically unbroken for long distances. *Block Mountains* are common in the great Basin. They are, as the term implies, blocks which have been elevated and tilted so as to constitute elevations above the general surface. It should be noted that all great earthquakes are thought to be connected with faulting. The California earthquake in 1906 is a case in point. Movements along an old fault sent vibrations through the rocks which produced the earthquakes.

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## FAULTS

Muscogee Folio, Okla., U. S. Geological Survey, 1906. Compare with Soil Survey of Muscogee Co., Okla., U. S. Bureau of Soils, 1913.

Austin Folio, Tex., U. S. Geological Survey. Compare with Soil Survey of Austin Area, Tex., U. S. Bureau of Soils, 1904.

Uvalde Folio, Tex., U. S. Geological Survey, 1900.

Tishomingo Folio, U. S. Geological Survey. Compare with Soil Survey of Tishomingo Co., Okla U. S. Bureau of Soils, 1906.

## CHAPTER III

## WEATHERING

**Erosion** is the general process by which all land surfaces are being broken down, carried away and deposited in the ocean. This process is so slow that it can be observed in notable action only in exceptional instances, yet, during geological time, the lands have been repeatedly elevated and worn down. It is a world-wide process, ever in operation and shaping the earth's surface.

Erosion may be considered under four heads: weathering, the process by which the earth's crust is broken up so that it can be carried oceanward; transportation, by which the comminuted rock is carried; corrosion refers to the wear and tear of rock materials carried by streams; deposition applies to the final laying down of the stream loads.

### Processes of Weathering

**Weathering.**—It is a matter of common observation that exposed rocks in time become less firm, sometimes change in color and finally are broken down. Smoothed surfaces of old monuments lose their polish and old and fresh rock surfaces in quarries are different. Weathering is the general term applied to the combination of processes by which rocks are broken down so that they can be carried seaward. The term was first applied to the action of frost and other atmospheric agents but is now used to include all processes by which rock is broken down. A rock is sometimes broken down with little change in its composition, a process termed *disintegration;* for example, when water freezes and pries open a rock, there is little or no chemical effect of the water. On the other hand, when a rock like granite, for instance, is not only broken into fragments by freezing and other processes of disintegration, but the composition of the rock is changed, the process is termed *decomposition.* Disintegration and decomposition practically always work together although one process is usually dominant at a given time and place; the one process is physical, the other chemical.

**Residual Soils.**—The soils due to weathering are termed *residual soils* because they are residues from which the soils are derived. A residual soil is a changing zone. The upper portions are being washed away while fresh soil is being made from the rock below, as shown in Fig. 64, where the underlying rock can be seen grading through different stages to the fine soil above.

FIG. 64.—Gradations from limestones below to soils above, Kansas.

### Processes of Decomposition

**Decomposition** is accomplished by four principal processes, *carbonation, oxidation, hydration* and *solution.*

**Carbonation** is a union of carbon dioxide ($CO_2$) with a base, a familiar example of which is the hardening of plaster by which the lime of plaster combines with the carbon dioxide of the air according to the following equation:

| Lime | and | Carbon dioxide | yield | Carbonate of lime | and | Water |
|---|---|---|---|---|---|---|
| $Ca(OH)_2$ | + | $CO_2$ | = | $CaCO_3$ | + | $H_2O$ |

Carbon dioxide is a gas which exists in the atmosphere in the ratio of about 3 parts of carbon dioxide to 10,000 parts of air. It is readily soluble in water, forming carbonic acid ($H_2CO_3$), so that most rain water and soil water contain varying amounts of this acid. In rain water it has been found in quantities 15 to 40 times greater than in air. This acid in rain waters explains the active etching of limestones and marbles by which the carvings and lettering are slowly obliterated. The carbonic acid attacks the calcite of limestones forming the soluble bicarbonate as follows:

| Carbonic acid | acting on | Calcite | yields | Calcium bicarbonate |
|---|---|---|---|---|
| $H_2CO_3$ | + | $CaCO_3$ | = | $H_2Ca(CO_3)_2$ |

In the soil atmosphere the amount of carbon dioxide may be relatively very great especially if the soil contains much organic matter. The soil air in some observed instances contains almost two hundred times as much carbon dioxide as the atmosphere. This is important from an agricultural point of view, for active carbonation in the soil changes the lime and potash into soluble carbonates.

Carbon dioxide is emitted in enormous quantities from active volcanoes; it is generated by fires and exhaled in the breath of animals. Carbonation is especially active in warm moist regions because the decay of the rank vegetation produces large quantities of this gas. When carbonation occurs the resulting minerals increase in bulk, thereby rupturing rocks and minerals, making them weaker and more porous and aiding the different processes of weathering. Much of the work of carbonation is done by the underground waters, and the process will be further considered under that topic.

### REFERENCE

A Treatise on Metamorphism, Charles R. Van Hise, U. S. Geological Survey, Monograph 48, 1904, Carbonation, pages 473-480.

**Oxidation** is the combination of elements and compounds with oxygen. Oxygen is a gas that exists in the atmosphere in the proportion of about 21 per cent of oxygen and 78 per cent of nitrogen. Like carbon dioxide, but to a much smaller extent, oxygen is soluble in water so that rain and soil water usually contain higher percentages than the air, and as a result, rain and ground water are active agents of oxidation. Oxygen is an active element and oxidation is, therefore, an active process. Active oxidation is conditioned on the presence of moisture, but in practically all parts of the earth there is enough moisture for this process. The process is especially active in the humid tropics, which are characterized by much heat and moisture.

Fig. 65.—Weathering has etched out delicate structures in limestone. (Phalen, U. S. Geological Survey.)

Iron oxidizes readily and, since iron is so widely distributed, the reddish iron oxides are much in evidence the world over. The iron oxides often cover soil grains in thin coatings so that the brilliant hues of many rocks and soils are somewhat deceptive, for when a red rock is analyzed, the proportion of iron is often surprisingly low. Oxidation, like carbonation, is accompanied by an increase in bulk, thus tending to break up the containing rock.

A common example of oxidation is seen when pyrite is oxidized according to the following reaction:

| Pyrite | and | Oxygen | yield | Iron sulphate | and | Sulphur |
|---|---|---|---|---|---|---|
| $FeS_2$ | + | 4O | = | $FeSO_4$ | + | S |

The iron sulphate is soluble and is often changed into other compounds. The sulphur may unite with oxygen and water to form sulphuric acid. Some rocks contain considerable pyrite and the changes noted above help to change the rock into soil.

## REFERENCE

A Treatise on Metamorphism, Van Hise, Oxidation, pages 461–473.

**Hydration** is the process by which water combines with various compounds to make *hydrated minerals*, a familiar example of which is the union of lime with water to form hydrated lime according to the following equation:

| Lime | combined with | Water | yields | Hydrated lime |
|---|---|---|---|---|
| CaO | + | $H_2O$ | = | $Ca(OH)_2$ |

Both in rocks and in soils hydration is important and extensive especially, as would be expected, in humid regions. The common rusting of iron is a familiar example of this world-wide process and hydrated oxide of iron ($Fe_2O_3 \cdot 3H_2O$) is very common in soils, giving them their reddish brown and yellowish colors. Limonite, the hydrated oxide of iron, is an important iron ore. Hydration, like carbonation, is accompanied by an increase in bulk. Thus, when anhydrite ($CaSO_4$) is hydrated and changed to gypsum ($CaSO_4 \cdot 2H_2O$), the well-known " land plaster," there is so great an increase in bulk that the rocks above gypsum deposits are frequently much broken and folded because of this expansion due to hydration. Merrill states that granites have been known to fall to pieces in a few days when removed from the quarry because of the hydrated condition of some of the minerals.

Many exposed rocks have red and yellowish coatings of iron oxides and hydrates on the outside while the interior is unchanged and of the original color. Thus a mass of black rocks (dike) in southeastern Pennsylvania can be traced for miles by the reddish boulders on the surface of the ground. The reddish and brownish stains of soils and subsoils are important indications of oxidation and hydration by the soil waters and air. A poorly drained and poorly oxidized subsoil is usually bluish or gray in color and when such soils have been properly drained and oxidized the reddish and yellowish colors due to oxidation and hydration often appear.

### REFERENCE

Van Hise, A Treatise on Metamorphism, Hydration and Dehydration, pages 481–483.

**Solution,** as the name indicates, is the dissolving of minerals in the ground or soil water. Pure water is a weak solvent, even dissolving quartz and feldspars in very small proportions, but pure water in rain or ground water is practically non-existent. Carbonic acid, as we have seen, is practically always present in rain and ground waters, and decaying vegetation produces acids that are effective solvents. In some portions of the tropics rain waters are found to contain considerable amounts of nitric acid which is believed to be caused by lightning.

A few minerals such as common salt go into solution unchanged in composition, but most soluble substances have been chemically changed from less soluble substances; this is especially true of the carbonates, which are by far the most common minerals in solution in ground waters. For the most part, solution is greatest in regions of heavy rainfall, which both furnishes abundant ground and soil water and promotes a heavy growth of vegetation which, upon decaying, yields acids to the underground waters. The influence of rainfall upon solution is especially well shown where the same soil types extend from dry to humid regions. For example, the reddish Orangeburg soils extend through the Coastal Plain from the Carolinas into Texas, but, as they extend into the dryer portions of Texas, their lime content becomes higher. Another inter-

Fig. 66.—Pitted limestone due to solution, Mo. (Marbut, Mo. Geological Survey.)

esting example is seen in Washington, where a belt of fine-grained soils extends from a very dry to a somewhat humid region. In the dry region, the soils are sandy, but as the rainfall almost imperceptibly increases the soils change to loams because the disintegrated sand grains decompose in part to clays.

The same effects are illustrated in the table below. It is usually surprising to persons used to soils in humid regions to observe the fertility of many arid sandy soils when they are supplied with water. However, it must be remembered that this sand is to a considerable extent simply fine grains of rock and not the residual sand of humid regions. This is well illustrated by Hilgard's comparison of soils subject to different quantities of rainfall, as follows:[1]

| | Humid regions average of 696 samples, per cent. | Transition region average of 178 samples, per cent. | Arid region average of 573 samples, per cent. |
|---|---|---|---|
| Insoluble residue | 88.21 | 83.50 | 75.87 |
| Potash | .21 | .33 | .67 |
| Soda | .14 | .32 | .35 |
| Lime | .13 | .70 | 1.43 |
| Peroxide of iron | 3.88 | 2.08 | 5.48 |
| Phosphoric acid | .12 | .21 | .16 |

Furthermore, the rate of water movement is an important factor in solution. Evidently slowly moving water will dissolve more than rapidly moving water, other things being equal. Porosity of rock aids soil solution to a certain extent both by allowing a more free movement of water and by exposing larger surfaces to solution. The temperature of water is a somewhat minor factor, but important during long periods; in general, the higher the temperature the more active is solution, which aids other weathering processes by leaving pores and cavities in the rocks, Fig. 166.

### REFERENCE

A Treatise on Metamorphism, Van Hise, Solution, pages 484–487.

**Association of Decomposition Factors.**—It should always be kept in mind that these processes of decomposition practically never act except in conjunction with each other, although, of course, one or more

[1] E. W. Hilgard, Soils, page 377, Edition of 1911.

may be more effective than others. Hydration and oxidation almost always act together and solution and carbonation are closely connected. The cooperation of hydration, carbonation and solution is illustrated in the equation given below. The orthoclase changes into insoluble quartz and kaolin and also into the soluble carbonate of potash, which is largely removed in solution.

| Orthoclase feldspar | and | Water | and | Carbon dioxide | yield | Kaolinite | and | Quartz | and | Carbonate of potash |
|---|---|---|---|---|---|---|---|---|---|---|
| $2KAlSi_3O_8$ | + | $2H_2O$ | + | $CO_2$ | = | $H_4Al_2Si_2O_9$ | + | $SiO_2$ | + | $K_2CO_3$ |

### REFERENCES

E. W. Hilgard, Soils, Chapter 2, Decomposition.

G. P. Merrill, Rocks, Rock Weathering and Soils, 1906, Part 3, pages 154–158; 165–174.

## Disintegration and Its Processes

**Disintegration,** as has been noted, is the breaking down of rocks by physical agents; it is promoted by several factors. **Temperature changes** producing *expansion* and *contraction* are probably the most widespread agents of disintegration. The effectiveness of these agents is well illustrated by the farmer's device of building a fire on a boulder and then chilling the rock with water, when large flakes of rock will scale off. The same action is seen in tropical regions when cool rain falls on hot rock surfaces. The disintegrating effects of temperature changes are due to the fact that all parts of a rock do not expand and contract at equal rates. In other words there is differential expansion and contraction by which stresses are set up which break the rocks. A rock composed of several minerals will be especially affected by temperature changes since its minerals expand at different rates and, moreover, the same mineral often expands at different rates along certain lines called axes. For example, quartz and hornblende expand over one ten-thousandths of their bulk during a temperature change of 50°, a small expansion to be sure, but so effective on a large surface that rock has been known to buckle and break. Thus, for example, when a rock like granite is heated, the closely packed minerals press against each other with great force and, when the rock is cooled, the minerals shrink away from each other; both the contraction and expansion produce tiny fractures even in the strongest rocks. Again, the larger the minerals the greater the mass expansion; for example, other things being equal, coarse granite would suffer more rupturing by temperature changes than fine-grained granite, and gabbro than basalt. It must be remembered that these changes, although extremely small, are continued from season to season and often from day to day. In a long period they break the strongest rock into fragments.

**Rapidity of Temperature Changes.**—Disintegration is best promoted by *rapid* changes in temperature because the rocks have little time to become adjusted to the resulting strains. One can, for example, bend steel or glass by slow pressure while they would break were the pressure applied suddenly. Regions of low humidity and high altitudes are especially subject to sudden temperature changes and consequently disintegration is especially prominent in deserts, in semi-arid regions and on mountain tops. In the Sahara the temperature differences between night and day are great so that rocks are visibly ruptured as night comes on. High mountain tops are nearly always covered with coarse, angular debris, for here the processes of disintegration are dominant and decomposition has little opportunity to reduce the rock fragments to smaller and less angular shapes.

Slower temperature changes are less effective but are worldwide. The seasonal changes between summer and winter extending perhaps to 30 or 50 feet are effective in the long run. Temperature changes, however, extend only to shallow depths as shown in the following table, which shows the temperature ranges in igneous rock (trap) and sandstone:[1]

| Depth below surface. | Trap Rock. | | | Sandstone. | | |
|---|---|---|---|---|---|---|
| | Max. | Min. | Range. | Max. | Min. | Range. |
| 3 feet................ | 52.85° | 38.88° | 13.97° | 53.15° | 38.25° | 14.90° |
| 6 feet................ | 51.07° | 40.78° | 10.29° | 51.90° | 38.95° | 12.95° |
| 12 feet................ | 49.00° | 44.20° | 4.80° | 50.30° | 41.60° | 8.70° |
| 24 feet................ | 47.50° | 46.12° | 1.38° | 48.25° | 44.35° | 3.90° |

**Soils Due Primarily to Disintegration.**—Disintegration explains why the soils of dry regions are typically "sandy," that is, they are composed of small angular pieces of broken rock rather than the more or less rounded grains of silica which compose most of the soils of humid regions. In other words, the soils of dry regions are comparatively

[1] Quoted from Forbes by Merrill, Rocks, Rock Weathering and Soils.

fresh; they are largely composed of small pieces of rocks which have suffered but little chemical change. On the other hand, the soils of humid regions are derived largely from rocks which have been decomposed and the soils have been leached as shown on page 71.

The peculiarities of arid soils are shown in the Fresno loam, of which a mineralogical determination is given in the following table:[1]

| Minerals other than quartz in | | Abundant and characteristic minerals in | | Remarks. |
| --- | --- | --- | --- | --- |
| Sand, per cent | Silt, per cent | Sand. | Silt. | |
| 30–50 | 50–70 | Hornblende, orthoclase, plagioclase feldspars. | Biotite hornblende. | Mineral grains distinctly angular with high content of plagioclase feldspars. |

It is evident first that these soils contain a high content of minerals other than quartz. Then the plagioclase feldspars which weather more easily than the orthoclase are especially abundant and in a fresh condition. Finally the angularity of the soil grains testifies to the slight amount of solution which they have undergone.

**Exfoliation.**—Rocks are poor conductors of heat, so that the rock a few inches below an exposed surface becomes much warmer or cooler than the interior. As a result of the differential expansion and contraction due to this, a crevice starts between the two zones of considerable and of small changes; this crevice is extended with successive temperature changes and eventually there is a scaling off of the outer shell, a process termed *exfoliation* or *spherical weathering*. Exfoliation is best developed in massive rocks, those having much the same structure throughout, because, if there are many differences either of composition or structure, the layers will crumble or break up instead of scaling off in large, thin flakes. Again, exfoliation is best shown in fairly strong rocks; shales and other weak rocks break off in small pieces rather than in large flakes. The process is effective from small pebbles to large mountain masses, as seen in Fig. 67.

**Other Factors.**—The *color* of a rock has an obvious effect in disintegration, for it is a well-known fact that dark-colored rocks absorb

[1] The Microscopic Determination of Soil-forming Minerals, by W. J. McCaughey and William H. Fry, U. S. Bureau of Soils, Bulletin No. 91, 1913.

more heat than light-colored ones. A minor but persistent factor is the *beating of rain drops*, the effect of which is seen on incoherent materials like mud, but it also acts less conspicuously on harder, firmer rocks.

*Freezing* is an important disintegration factor over large areas where the temperatures reach the freezing-point of water. Water in solidifying expands about 9 per cent of its bulk with a force of 150 tons to the square foot, a pressure which will easily rend strong iron pipes or perceptibly raise a building. It is readily apparent that, once water penetrates rock, its great expansive power in freezing will break the strongest rock. Cracks, joints, bedding planes or planes of schistosity all furnish comparatively easy entry for water and also are lines of weakness which

FIG. 67.—"Enchanted Rocks," Texas. The hills are of granite and show exfoliation on a large scale. (Paige, U. S. Geological Survey.)

readily yield to ice expansion. Water also enters the pores of rocks, but here the ice work is sometimes not so effective unless all the pores are filled, since the ice can to some extent expand into adjoining vacant pore spaces. Like many other weathering processes, the rending by ice is somewhat cumulative; each freezing leaves a crevice somewhat larger and deeper than before and makes succeeding effects easier.

**Freezing and Thawing.**—This process is especially effective in regions of repeated freezing and thawing, such as many mountain tops, which are often so covered with angular debris that the underlying rocks cannot be seen. On some mountains one can often note with considerable certainty where the less angular debris due to weathering changes to the angular debris due largely to disintegration by freezing. Indeed, some geologists hold that the active weathering due to disintegration on mountain tops is so effective as to limit mountain growth, that is, according to this theory, mountains cannot be elevated above a certain height because of the increasing effectiveness of disintegration. Cleopatra's needle is often mentioned as an illustration of the effectiveness of freezing. This granite obelisk had stood for centuries without injury in the warm, equable climate of Egypt, but, when removed to New York, the inscriptions soon began to show the effects of repeated freezing and thawing, and it was found necessary to coat the surface with paraffin to keep out the water.

One of the beneficial effects of fall plowing is due to freezing; fragments of rock are broken and the plant food made more easily available and, furthermore, the heaving of the soil leaves it more open so that the tilth is improved. This breaking up of soil particles is well illustrated by feldspar pebbles found in the western High Plains. These pebbles have been rounded by water action, but freezing water acting along the lines of easy cleavage in the pebbles has broken many of them into somewhat angular, smaller shapes. The farmer in cool regions is often puzzled by the recurrence each spring of a new crop of stones to be picked. The explanation lies in the fact that, as the water in the soil freezes, the rocks are pushed upward by the expansion and do not sink back so far as the finer materials when the soil thaws and, as a result, the rocks and pebbles are left nearer the surface which they finally reach.

Fig. 68.—Residual boulders surrounded by soft, disintegrated granite. (Weed, U. S. Geological Survey.)

**Gravity** is an important weathering factor on slopes, its importance increasing with the steepness of the slopes. On all slopes there is a movement down slope of the mantle rock, a movement usually imperceptibly but fairly continuous. Soils and mantle rock are thereby carried down slope, leaving the rocks on upper slopes less protected and thereby the more exposed to weathering.

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E. W. Hilgard, Soils, Chapter 1, Disintegration.

G. P. Merrill, Rocks, Rock Weathering and Soils, 1906, Part 3, pages 158–163; 175–180.

### The Weathering Work of Plants

The weathering work of plants is materially conditioned by climate and soil. In the moist, hot tropics where plants grow in profusion, this work is very important, while in cold or arid regions or on rocky slopes the work of plants may be of slight importance. On the whole plants favor decomposition rather than disintegration, but a heavy growth of plants often in some measure protects from weathering.

**The Work of Roots.**—The prying effect of roots is a common occurrence. A root, starting in a crevice, joint or some plane of weakness, extends inward and at the same time increases in diameter and so widens the opening. Roots in their successive descent push the soils back and forth and so render them more open, an effect well shown where trees are set out in a stiff hard pan and the roots finally break up the hard pan. In Florida, for example, pineapples are set out in a friable limestone which the roots penetrate and break up. The roots of grains penetrate to a considerable depth, and alfalfa roots have been found at depths of 30 or more feet and the intricate tangle of corn roots sometimes penetrates to depths of 6 feet or more and they extend for varying distances from the plant. The overturning of trees stirs the soil to a considerable depth and brings relatively fresh soil to the surface, there to be exposed to active weathering.

Roots have a solvent action, as is shown by the familiar experiment of growing plants on a polished marble surface where the root paths may be traced by faintly etched lines of roughened surface. Roots, tree roots especially, when they decay provide paths for descending water. A bare rock surface in a humid climate is soon covered with a growth of mosses and lichens which keep the surface damp, the rootlets penetrate crevices and the decaying plants furnish acids which attack the rock, all of which convert the rock into soil and prepare it for a growth of higher plants. Plant roots bring to the upper soil some of the soluble compounds from below and so promote an interchange of materials. From an agricultural point of view this bringing up of compounds of potash and phosphoric acid is of considerable importance.

**Decay and humification** are extremely important in weathering work of plants. When leaves, stems and trunks fall to the surface of the ground and are freely exposed to the air, they change for the most part to carbon dioxide ($CO_2$) and water. A portion of the carbon dioxide is dissolved in the rain water, carried into the soil and performs the work which has been described in preceding pages. On the other hand, when vegetable matter falls into water or on moist surfaces, there is less access of oxygen and complete decay does not occur. Roots and other parts of plants under many conditions are surrounded by soil so moist much of the time that they do not completely decay. The organic matter resulting from such incomplete decay is termed *humus*. It is the substance that gives the dark color to so many productive soils so that a dark soil is commonly regarded as productive and modern agricultural methods emphasize the creation of humus if it is not already present. The term in agricultural literature is commonly used somewhat indefinitely, sometimes meaning simply decomposed vegetable matter and, again, vegetable matter so decomposed and changed into a black waxy substance that nearly all traces of plant remains have disappeared.

Humus is abundant in favorable locations and scarce in others. In arid soils it forms very slowly if at all. Hilgard found the average humus percentage in arid uplands to be only 0.91 per cent and in soils of humid climates, 4.58 per cent. Moisture favors the growth of vegetation and, under favorable conditions, protects the vegetable matter from the air, thus preventing a rapid oxidation so that humus is notably developed in two localities, swamps and humid prairies. In swamps it accumulates and often forms peat. On prairies in the humid regions there is commonly a deep layer of humus. The black soil in the Iowa corn belt is often 6 feet deep and the Marshall silt loam, a very productive prairie soil of loessial origin, has a deep layer of soil mingled with humus. The distinctive feature of prairies which favors the accumulation of humus is their level or gently rolling surface, which prevents too rapid drainage, keeps the soil fairly moist and so favors the slow decomposition which results in humus. There seems to be a difference not well understood between the humus of prairies and that of swamps; the former will endure long cultivation while the latter is rapidly oxidized and disappears with a few years of cultivation. The large amount of humus in prairie and other soils is doubtless due in large measure to the decay of roots since a close correspondence has been noted between root growth and the distribution of humus. Other things being equal, soil texture has a considerable effect on the formation of humus. The lighter soils such as sandy loams or sands allow free access of air by which vegetable matter is rapidly oxidized and, moreover, they favor rapid soil drainage so that the soil is not moist for long enough periods to favor the accumulation of humus. The Houston soil series in Texas affords a good example of the effects of soil texture. The usual soils in this series are heavy but small areas of sandy loam are frequent. The clay loams of this series contain 6.31 per cent of vegetable matter while the fine sandy loams contain only 2.38 per cent.

**Weathering Effects of Humus.**—Humus is so important agriculturally that its formation has been considered in some detail, but it should not be forgotten that it is an agent of no small importance in soil weathering. Because of its porosity humus absorbs and retains moisture which is effective in soil solution work. The absorbtive qualities of humus will be apparent from the following table compiled by Lyon and Fippen.[1]

Per Cent of Water in Soils at Saturation

| | |
|---|---|
| Coarse sand | 40.5 per cent |
| Fine sandy loam | 38.0 per cent |
| Clay | 54.5 per cent |
| *Humus* | 333.0 per cent |

Humus expands with moisture and contracts upon drying and these movements, together with the porosity of humus itself, tends to keep soils, especially heavy soils, open for the movements of air and moisture. Humic acids, mainly carbonic acid, are generated when humus is oxidized. Thus humus has important weathering effects, both chemically and physically.

## REFERENCE

Lyon, Fippen and Buckman, Soils, their Properties and Management, Macmillan, 1915, Chapter 8, The Organic Matter of the Soils.

**Microorganisms,** mainly *bacteria* and *fungi*, break down plant tissues and so promote the formation of humus. These organisms are sometimes found in enormous numbers; Mayo and Kinsley found a black loam in Kansas which contained over thirty million bacteria per cubic centimeter, but not all these organisms are active in the production of humus. The work of these organisms is practically confined to a shallow soil zone beneath the surface. Acids in the soil or subsoil retard the growth and activity of microorganisms; if a soil is calcareous the acids are neutralized and the soil is more favorable to the action of these small forms. This is one of the reasons why so many limestone soils are high in humus and dark in color. For example, the

[1] Soils, Lyon and Fippen, New York, 1910, page 161.

soils of the Houston series are derived from a clayey, "rotten" limestone which weathers for the most part to heavy, calcareous soils which, because of their color, give their name to the productive "Black Belt" of Alabama and Mississippi.

**Bacteria.**—The enormous numbers of these small plants and their importance on the formation of humus in some soils have been noted. The work of many of these bacteria is but little understood but some groups are of interest from a weathering standpoint. One group, the nitrifying bacteria, converts ammonia compounds into nitric acid and nitrates while others convert nitrates into simpler compounds. The root bacteria, Fig. 69, of legumes such as peas, clover and alfalfa obtain nitrogen from the air and furnish it to the plants from which some nitrogen in some form remains in the soil.

FIG. 69.—"Lumps" of root bacteria growing on alfalfa roots. (C. W. Edgerton.)

### REFERENCES

H. W. CONN, Agricultural Bacteriology, Part 2, Blakiston, 1918, pages 41–137.
J. G. LIPMAN, Bacteria in Relation to Country Life, Macmillan, 1908, Part 4, pages 135–302, Bacteria in Relation to Soil Fertility.

## The Weathering Work of Animals

The work of animals in promoting weathering is mostly performed by those of burrowing habits. Such work, therefore, is largely confined to rock that is already broken up, and since animals do not burrow far below the surface, their work is for the most part confined to the soil zone. These animals bring up lower soil to be acted on more or less vigorously by weathering agents and their burrows allow easy entry of air and water. The geologist and soil surveyor is often helped in his work by observing the deeper materials thrown out by burrowing animals.

In humid climates probably the most important animal from a weathering standpoint is the earthworm. Darwin, in his classical researches, estimated that in some soils there are 50,000 earthworms to the acre and that in half a century these earthworms will work over from one-half to an entire surface foot of soil. They pass the soil through their bodies to get its vegetable matter and so break up and decompose the soil particles. In poorly drained areas the crawfish does considerable weathering work as a burrowing animal. The term "crawfish land" indicates the activity of these animals and the accompanying poor drainage. The work of ants is important in the tropics but of much less importance in temperate climates. Ants bring soil to the surface and their connecting underground passages extending for miles afford opportunity for the entrance of air and water. They carry underground food such as leaves and other vegetable matter which, in decaying, yields carbon dioxide.

### REFERENCES

N. S. Shaler, Origin and Nature of Soils, 12th Ann. Report, Part 1, U. S. Geological Survey, Animals and Plants in Soils, pages 268–287.

Van Hise, A Treatise on Metamorphism, Weathering Due to Plants and Animals. Decomposition, pages 452–457; Disintegration, pages 444–451.

### Interaction of Weathering Factors

It should be kept in mind that weathering processes, both chemical and physical, not only go on together but are mutually helpful. It is seldom that every process is equally effective at a given time and place, but one or another process is usually dominant and, where all processes operate actively together, weathering goes on very actively. It has been noted that disintegration is dominant in arid regions while decomposition is very prominent in humid regions. Disintegration by expansion and contraction and by freezing breaks up rock and so paves the way for more effective action by the agents of decomposition. For example, a cube of rock one inch square exposes six square inches to weathering; if this cube be broken into four equal cubes, there will be a much larger area exposed. Again, if this cubic foot be comminuted to the texture of ordinary loam, there is a total surface according to King of about an acre and, according to the same author, in a fine clay there is as much as four acres of exposed surface. When it is remembered that, in humid regions, the small soil grains are often surrounded by films of capillary water and that this water is decomposing the soil grains, it is at once clear that the breaking up of rocks and soils into very fine particles is an important aid to weathering. It is also evident in this connection that the rapid increase in water-holding capacity as soil particles become smaller is an important weathering factor.

The figures given above are only estimates, but they will give an idea of the great aid which disintegration renders to decomposition by breaking up the rocks and soil particles. The pores, crevices and other spaces made by the processes of disintegration facilitate the entrance of air and water which attack the minerals. Conversely it has been seen that oxidation, carbonation and hydration are accompanied by increases in bulk which tend to disrupt the rocks and to further assist disintegration. It has been calculated that, in the change from granite to soil, there is an increase in bulk of 88 per cent provided there is no loss of materials, but this statement is useful mainly for illustration since there is always some loss of materials; the statement will, however, show the potency of an increase in bulk in hastening weathering processes. Again, it should be remembered that hydration, oxidation and carbonation very seldom operate separately but work simultaneously. Especially are oxidation and carbonation commonly associated but, while oxidation and carbonation are mainly limited to a relatively shallow zone, hydration can and does occur whenever water is present in the rocks, even to great depths. Probably carbonation is the most variable process since, while carbon dioxide is universally present in the air, its content in the ground water is variable. The weathering products of minerals are nearly always much weaker than the original minerals. Hornblende and feldspars, for example, weather to incoherent quartz and clays.

## Rate of Weathering

Probably the most complete and rapid weathering is to be found in the humid tropics where high temperatures, much moisture and abundance of vegetation combine to provide very favorable conditions for decomposition. Leaching is very complete and residual products are rich in hydrated minerals. Here is found a mantle rock to which the term *laterite* is applied. It is a reddish material in which the parent rocks seem to be entirely decomposed, even durable silicates being completely broken up and changed. Rocks under favorable conditions in the tropics have been weathered to depths of two hundred feet or more. In arid regions, both hot and temperate, the conditions are highly favorable for disintegration since there is little moisture for decomposition. The dry air is conducive to great and sudden temperature changes which produce marked expansion and contraction and freezing and thawing are active in deserts of the temperate zones.

Altitude on the whole favors disintegration. As altitude increases the cold becomes greater and daily and seasonal variations are more marked and when the altitude is sufficient for freezing this factor is added to the forces of disintegration. Furthermore, high altitudes are likely to be characterized by more or less steep slopes which add to the rapidity of weathering. The greatest effect of freezing is found in the temperate zones where alternate freezing and thawing repeatedly occur during a single winter. Here also are found the much less important temperature variations between summer and winter which are effective to greater depths than are daily variations. In the polar regions the temperature variations and freezing and thawing are of small importance since, excepting a thin veneer of soil, the ground is frozen to a considerable depth all the year around. The body of a mammoth, an animal extinct for thousands of years, was found frozen in Siberia, a fact that indicates that the ice in that region has been preserved since early Pleistocene times. A minor effect, but very interesting for local study, is the contrast in weathering on north and south slopes. In the Northern Hemisphere snow and freezing persist longer on northern slopes but vegetation is usually heavier on southern slopes. It has been observed in the mountains of the Carolinas that, other things being equal, the soils on northern slopes are likely to be darker in color than those on southern slopes. In other words, decomposition is less active on the northern slopes and the soils are likely to contain more humus.

## REFERENCES

Van Hise, A Treatise on Metamorphism, Rate of Weathering, pages 532–534.

Ries and Watson, Engineering Geology, Wiley & Sons, 1914, Chapter 4 (general treatment).

## CHAPTER IV

# RESIDUAL SOILS FROM VARIOUS ROCKS

## LIMESTONE AND MARBLE SOILS

**Introductory.**—Limestone soils are proverbially fertile and of large extent. It will be remembered that the basic mineral in limestone and marble is calcite ($CaCO_3$), which is readily soluble in water. However, limestone in nature is practically never pure. Because of its mode of formation, there are almost always varying amounts of clay and sand, so that limestones grade into shales through the argillaceous (clayey) limestones and into sandstones through the aranaceous (sandy) limestones. Clayey limestones typically yield heavy soils such as clays and silts. Sandy limestones often yield loams and silt loams. A very common impurity is silica ($SiO_2$) in the form of flint or chert, which may occur in small grains and is often distributed in nodules or layers as shown in Fig. 36. The chert and flint dissolve very slowly as compared with the enclosing limestone and are left in the residual soil as gravel or small rocks, thus often forming a stony or gravelly loam. For example, the widespread Clarksville series of soils is derived from a somewhat siliceous limestone and the soils are often somewhat stony and cherty.

A limestone soil represents the residuum of a large mass of rock that has been carried away in solution. Pumpelly, in describing the weathering of limestones in the Missouri Ozarks, estimates that the residual insoluble materials from 20 to 120 feet in depth have been derived from not less than 1200 feet of limestones. In southern Wisconsin there are residual clays with an average depth of about 10 feet and Whitney estimates that these were derived from the decomposition of from 350 to 400 feet of formerly overlying limestone and calcareous shales. These estimates are little more than suggestions and are probably underestimated since much of the residual material has been washed away.

**Clay Soils from Limestone.**—The principal impurity of limestone is clay, which, being practically insoluble, remains after the calcite has been dissolved and carried away; it is, therefore, clear that limestone soils are typically clays and silts. Limestone soils are proverbially fertile although, contrary to a common impression, they do not necessarily contain much lime since the lime carbonate is more or less leached out. Indeed a common practice in many limestone regions is to lime the soils somewhat frequently to correct soil acidity. Limestone soils

FIG. 70.—Limestone and its residual soil. The rock which yielded the soil was many times thicker than the present zone of soil and mantle rock. (U. S. Geological Survey.)

are often reddish either in the soil or subsoil unless they contain enough humus to make them dark. The reddish colors are due to finely divided oxides of iron which coat the clay and silt particles, the colors being a result of the long-continued oxidation which the soils have undergone.

**Soils from Cherty Limestones.**—Chert weathers slowly; when it is pure the weathering is almost wholly by disintegration—freezing and thawing and contraction and expansion being especially prominent. Most cherts, however, have small amounts of calcite scattered throughout and these are dissolved out leaving the chert pitted and porous.

Furthermore, cherts are very slowly soluble in alkaline water which is commonly found in limestone; under weathering they often change from hard, firm chert to a soft, porous " cotton rock " which can be picked apart with the fingers. Hence it is that the slowly weathering cherts and flints remain in limestone soils long after the limestone has been dissolved and soils from cherty limestones are often stony or gravelly. If weathering has been in progress for a long time, the cherts are often broken into fine particles and the soils are somewhat sandy in consequence.

**Soils from Dolomitic Limestones.**—Dolomitic (magnesian) limestones are widespread. These limestones weather more slowly than ordinary limestone and, where the two are in the same locality, the

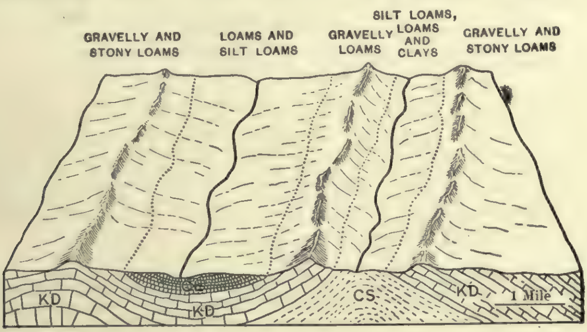


Fig. 71.—Diagram to illustrate the topography and soils from cherty dolomitic limestones, limestones and sandstones and shales in northern Georgia.

(*KD*), Knox dolomite; (*CS*), limestones; (*CL*) sandstones and shales. (Data from U. S. Bureau of Soils and U. S. Geological Survey.)

dolomitic limestones usually make the higher topography. On a small scale this differential weathering is often shown where the dolomitic portions of a limestone weather slowly and stand in relief. This is especially well shown in the Appalachian Ridges of Tennessee, Georgia and Alabama where the Knox dolomite, an important soil-making formation, underlies most of the ridges, the valleys being underlain by weaker limestones and shales. The formations in this belt have been folded so that they are repeatedly brought to the surface as shown in Fig. 71. The residual soils illustrate many of the preceding principles and are, therefore, worth a somewhat detailed consideration.

A somewhat typical illustration is shown in Fig. 71. The Knox dolomite (*KD*) here is a somewhat massive magnesian limestone which contains considerable flint. Both because of its silicious composition and its slowly soluble magnesian carbonate, this rock has been less eroded than purer limestones and shales and it stands up as roughly parallel ridges. The residual soils of the different rocks show interesting variations. The Knox dolomite (*KD*) yields a silt loam, but this formation contains much silica in the form of flint and chert arranged both as nodules and as thin layers. The silica weathers very slowly so that chert of various sizes and angular shapes is scattered through the soil and subsoil. Layers of partly decomposed chert are found in their original position in the subsoil. The soil is a gravelly or a stony loam and the surface contains much more stony matter than the subsoil because the finer particles have been carried away, leaving the coarser chert fragments behind. The Chickamauga limestone (*CL*) varies from fairly pure limestone to clayey limestone. From the former is derived a deep silt loam and from the latter, a clay soil. The more soluble lowland. has weathered to a gently rolling limestone

FIG. 72.—Weathering of cherty dolomitic limestone. The white portions (chert) are less weathered and project. (Mo. Geological Survey.)

A silt loam is derived from the Conasauga shale (*CS*), a formation mostly of shale but with interbedded limestone and limey shale. Local areas of fairly pure limestone yield clay soils and cherty areas yield loams. In places the original stratification of the shales is still preserved in some of the subsoils.

**Chemical and Mineralogical Changes.**—The changes in composition from a fresh limestone to its residual clay are illustrated in Fig. 73.

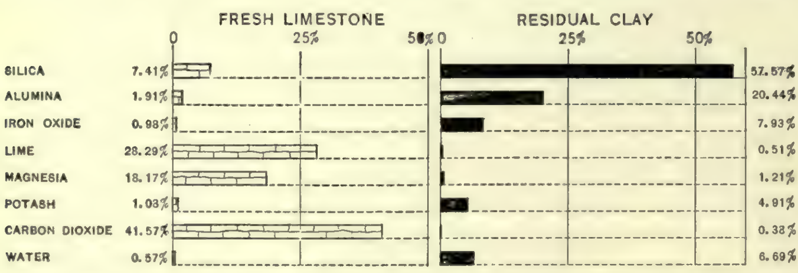


FIG. 73.—Diagram showing the compositions of fresh magnesian limestone and its residual clay. (Data after Merrill.)

The fresh rock is a magnesium limestone composed largely of lime and magnesium carbonates with some silica and a little potash and iron. The residual clay is of a deep-red color as indicated by the considerable percentage of iron oxides. The great losses involved in the change are, of course, the soluble carbonates of lime and magnesia, while the great relative gains in the residual soils are in the silica, alumina and water which go to make up the residual clays. The iron has dissolved much less rapidly and shows, therefore, a relative increase and the percentage of potash in the clay is largely due to potash feldspar in the original limestone, for the feldspars have not completely dissolved but remain in the residual clays.

The following mineralogical analysis of a limestone soil (Hagerstown series) throws some light on the processes involved in the origin.[1]

| Minerals other than quartz in | | Abundant and characteristic minerals in | |
|---|---|---|---|
| Sand, per cent. | Silt, per cent. | Sand. | Silt. |
| 5–8 | 8–10 | Secondary quarts crystals, weathered orthoclase. | Altered feldspar. |

In the first place there is a total absence of recognizable calcite in the sands and silts. The clays are not adapted to microscopic study and, therefore, they do not appear in these tables. By secondary quartz is meant quartz that has been deposited in the limestone since it was formed. These tiny quartz particles are often crystallized and show the characteristic six-sided pyramids so familiar in large crystals. It is clear that solution is eminently active in the weathering of limestone, at least in humid regions. If a limestone is coarse-grained there is some disintegration, but this process is relatively less important in limestones than other rocks.

**Topography.**—Another soil factor in limestone regions is the topography. Owing to the easy weathering of limestone the surface is often low and level or rolling. There is, for example, a stretch of level, rolling limestone country along the Great Valley which extends from New Jersey to Alabama. The Black Belt in Alabama and Mississippi and the Black Prairie in Texas are prairie like belts underlain by weak (" rotten ") limestone and calcareous shales. The relatively level surface, as we have seen (page 79), favors the accumulation of humus, hence the local names. The dolomite ridges of the Appalachian Ridge Belt, Fig. 71, illustrate another relation between topography and limestone soils. The rocks of these ridges, being more resistant than the neighboring limestones, form ridges which are elevated and have

[1] McCaughey and Fry, loc cit.

rather steep slopes. As a result, the soils are prevailingly stony because most of the finer soil particles are washed away.

**Notable Regions.**—Limestones are widely distributed both in large and in small areas. The limestone belts in the South have been noted in the preceding paragraph (see Fig. 251). Long limestone valleys together with the great Appalachian Valley in the Appalachian Ridge Belt afford limestone soils (Figs. 49 and 55). The Blue Grass Ba ins in

Fig. 74.—Soils derived from limestone in the foreground. The ridge in the background is underlain by sandstone and is covered by a stony loam. (U. S. Bureau of Soils.)

Kentucky and Tennessee are floored with limestone soils (Fig. 59) and there are large areas in the Ozarks of Missouri and Arkansas.

### REFERENCE

H. H. Bennett, Soils of the Limestone Valleys and Uplands Province in Soils of the United States, Bull. 96, U. S. Bureau of Soils, 1913; general, pages 85–89, Soil Series, pages 89–108.

## SANDSTONE AND QUARTZITE SOILS

### Sandstone Soils

**Introductory.**—In general it will be remembered that sandstones are predominantly composed of silica and that they themselves are products of long-continued weathering. For example, granite after long-continued weathering changes mainly into quartz and clay; the quartz and clay are usually separated by stream action, the quartz forming sandstone and the clays shales. The quartz grains forming the bulk of most sandstones are, therefore, very resistant to weathering. Nearly all sandstones contain a considerable proportion of silt and clay so that the soils derived from apparently coarse, pure sandstone are often surprisingly heavy, often being loams or heavy sandy loams rather than sands. Other sandstones are calcareous, but calcareous sandstones are much rarer than calcareous shales and there are not so frequent gradations between sandstones and limestones as between sandstones and shales.

There is an important soil relation between the size of grains in the parent sandstone and the texture of the residual soil. Obviously a coarse-grained sandstone will yield a coarse-textured sandy soil and a fine-grained sandstone a fine-grained soil. Furthermore, a fine-grained sandstone is deposited by relatively slow currents and is, therefore, likely to contain considerable fine materials as clay, silt and fine sand. Hence it is that fine-grained sandstones and sandy shales often yield silt loams and very frequently they yield loams.

**The weathering of sandstones** is simple and consists mainly in the solution of the cements. As soon as the cement is dissolved the grains fall apart and the sandstone crumbles into soils. Calcareous cements dissolve easily, iron cements dissolve less easily and quickly and sandstones with siliceous cements, especially the quartzites, are very resistant to weathering, especially solution. In fact the weathering of quartzites and sandstones with siliceous cements is mainly by disintegration; instead of breaking into the original grains, the rock tends to break into flakes and angular fragments and to yield a shallow, gravelly soil. Sandstones for the most part readily yield to disintegration. Many sandstones are stratified and the planes of stratification are planes of weakness and, moreover, sandstones, as a rule, are porous and absorb considerable quantities of water which, in freezing rifts and flakes the rock.

## Quartzite Soils

Quartzites are not widespread and so far as area is concerned they are not important as soil makers. Owing to their hardness and tenacity these rocks are extremely resistant to erosion and almost always underlie rough and relatively high country. Again, their slow weathering makes for a slow formation of soil so that quartzite soils are usually shallow, siliceous and unproductive. Stony loams are perhaps the predominant type.

**Fig. 75** shows a section of the closely folded metamorphic rocks of the Piedmont Plateau in southeastern Pennsylvania. The Chester series is for the most part derived from schists; the soils are known locally as "gray lands." The Chester loam in this area is derived from granite-like gneiss. Both soil and subsoil are silty

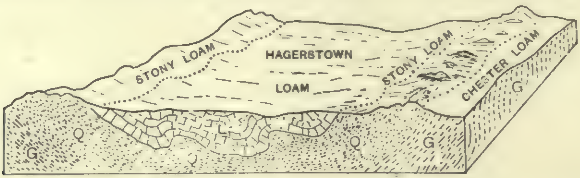


Fig. 75.—Diagram to show the occurrence of rocks and their derived soils on the Piedmont in Pennsylvania. The rocks are closely folded and include gneiss (*G*), quartzite (*Q*) and limestone (*L*). Length of section about seven miles. (Data from U. S. Bureau of Soils and U. S. Geological Survey.)

and typically they contain considerable amounts of stony fragments. The *quartzitic sandstone* weathers relatively slowly and yields a stony loam of low fertility and a hilly topography. The limestone yields loams and silt loams of the Hagerstown series.

## SHALE AND SLATE SOILS

### Shale Soils

Shales, like sandstones, are composed of materials which are the results of long-continued weathering and are, therefore, but little affected by decomposition. The clays, their principal constituent, have been derived from the more or less thorough weathering of other rocks and are comparatively stable. The main evidence of weathering in shales is the frequent oxidation of their iron compounds which results in reddish and yellowish colors. Shales practically always contain considerable sand and they grade into the sandy shales and into the shaly sandstones. On the other hand, the shales may become more calcareous and grade into shaly limestone. Many of the black calcareous soils of the Gulf Coastal Plain are derived from these calcareous shales. Shales are often interstratified with layers of sandstone or sandy shales in which the sand grains are small and these are not infrequently interspersed with thin beds of limestone, and the weathering of such strata frequently yields heavy loams or silt loams. Shales which are finely stratified tend to disintegrate into small flat plates which weather slowly and remain in the soil, yielding shale loams. Such fragments also occur on slopes where the finer materials have been washed away.

Mineralogical analyses of two soil series derived from sandstones and shales are as follows: [1]

| | Minerals other than quartz in | | Abundant and characteristic minerals in | |
|---|---|---|---|---|
| | Sand, per cent. | Silt, per cent. | Sand. | Silt. |
| Penn series... | 5 | 20 | Orthoclase much altered, hematite. | Decomposed feldspar. |
| Dekalb series. | 2–3 | 8 | Orthoclase very much altered. | Tourmaline. |

The point of particular interest in the table is the greater amount of other minerals than quartz in the Penn series, and this has a close relation to the origin of the parent rocks. The Penn series is derived from Triassic sandstones and shales, and these rocks were largely derived from the wear of granites and from other igneous rocks which were not far distant. Therefore the Penn series naturally shows a high percentage of undecomposed minerals, especially the feldspars. The Dekalb soils, derived from sandstones and shales, are important soils east of the Mississippi. They show a low per cent of minerals other than quartz.

## Slate Soils

Slates weather in much the same way and to much the same final products as shales. This is expectable since slates are for the most part metamorphosed from shales. Micas are usually developed during the metamorphism from shales to slates but generally the grains are sc small that they have little effect on the soils except to make them somewhat more open textured. Quartz is often formed, as in gneisses and schists, in long bands or " stringers," and these often remain in the soils in considerable quantities. The fine cleavages of slate render it easy for the action of disintegrating processes so that the slate breaks up into thin, flat plates, but these plates, because of their firmness and hardness, do not decompose readily; they occur in practically all slate soils and, when numerous, they give rise to the characteristic slate loams. When completely decomposed, slates yield fine-textured soils, and most of the slate soils that have been described are silt loams.

[1] McCaughey and Fry, loc. cit.

Slate outcrops are usually narrow and, therefore, are not important as soil makers and, furthermore, these outcrops usually occur in mountainous regions of highly folded rocks where soils are of little agricultural importance. There is a considerable area of slate soils in the North Carolina slate belt and some of these soils have considerable agricultural value. The soils of a portion of this belt are shown in Fig. 76 where the Allamance series is derived from dense, fine-grained, bluish slates and which yield silt loams.

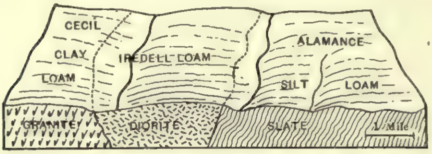

FIG. 76.—Residual soils from slate, diorite and granite, N. C. (Data from U. S. Bureau of Soils.)

**Comparison of Sedimentary Rocks.**—The combined compositions of limestone, shales and sandstones are shown in Fig. 77. The preponderating minerals of limestones are calcite and dolomite, that of sandstone is silica with a small amount of alumina which is contained mostly in the clay and a still smaller amount of calcite which is mainly a cement. In shales, the alumina and silica are to a great extent combined in a silicate, kaolin, which is the essential mineral of the clays.

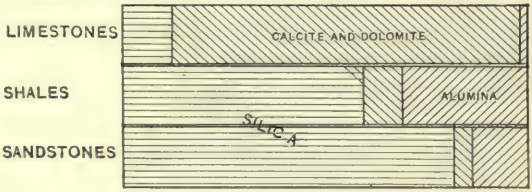

FIG. 77.—Generalized diagram to show the composition of limestones, shales and sandstones. (Data after Clarke, U. S. Geological Survey.)

Some soil belts from sedimentary rocks are found in eastern Kansas, Fig. 78. The rocks, dipping in a westerly direction, expose their outcrops, which yield roughly parallel belts of soils. The shale yields a silt loam underlain by a clay subsoil. Next to the

FIG. 78.—Residual soils from sedimentary rocks, Kansas. (Data after U. S. Bureau of Soils.)

westward is a formation including thin beds of shales and fine-grained sandstones which yield loams and sandy loams. Overlying this is a thick bed of limestone marked by a belt of deep red-clay loams. The uppermost formation is a friable sandstone which to a casual observer is almost pure, but it contains so much clay and silt that its soils are mainly sandy loams instead of sands.

### REFERENCES—RESIDUAL SOILS FROM SEDIMENTARY ROCKS

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## Granite and Gneiss Soils

It appears from geological investigations that rocks of granitic composition have the greatest surface exposure of any igneous rocks and they are, therefore, very important as soil makers. Granites and gneisses can be considered together because their composition is much the same. They belong to the acid group of igneous rocks, that is, rocks with high percentages of quartz. Both rocks have in considerable abundance quartz and feldspars, especially orthoclase (the potash feldspar) and, to a less extent, micas, hornblende and small percentages of apatite, the phosphorus-yielding mineral. The gneisses, however, have a much larger percentage of accessory minerals but these usually compose only a small percentage of the entire rock. The chemical weathering or decomposition, therefore, of both granites and gneisses can well be considered together.

**Weathering of Granites and Gneisses.**—The first minerals to show weathering are usually the feldspars. The two cleavages of these minerals are double lines of weakness, and even when the minerals are comparatively fresh there are often faint whitish lines along the cleavages indicating initial decomposition. That the feldspars weather rather readily is shown in many fresh, sound granites where the smooth faces of some of the feldspars appear " chalky." This appearance indicates that the feldspars are beginning to decompose, a process which ends with the solution of the alkaline compounds and the accumulation of clay and sand as shown in the equation on page 73. Since orthoclase is a prominent mineral in granites, it is apparent that granitic soils in general are fairly well supplied with potash. Hornblende and mica are usually found in varying quantities in all granites. Hornblende, owing to its easy cleavages, disintegrates rather quickly and decomposes, setting free iron compounds, clay, sand and carbonates of lime, magnesia, soda and potash. Mica, while it disintegrates easily, is slow to decompose and often remains in considerable quantities in the soils. Muscovite, the potash mica, upon final decomposition, yields a small quantity of potash.

Both gneisses and granites readily disintegrate into coarse particles, the process being aided by the variety of minerals and their various

FIG. 79.—The change from fresh to weathered granite and to soil, Md. (Md. Geological Survey.)

colors which tend to produce differential expansion and contraction. In addition, the gneisses have a markedly schistose structure which causes the rock to split rather readily along the planes of weakness. The quartz in gneisses is very likely to occur in bands or "stringers" instead of in grains as in granite. Soils from gneisses are, therefore, likely to contain these undecomposed masses of quartz as gravel, locally in such quantities as to render the soil sandy or gravelly. From this feature it is often easy to determine the gneissic origin of a soil even when the bed rock cannot be seen.

**Chemical and Mineralogical Changes.**—The general facts as to the weathering of granites into soils are illustrated in Fig. 80, in which the compositions of fresh rock and its residuum are compared. The rock, as described by Watson, is a fine-grained, blue-gray granite showing quartz, feldspar, biotite and muscovite. The weathered zone is about 20 feet in depth, grading from fresh granite upward into reddish, discolored, crumbly granite and, finally, into a deep red clay, somewhat gritty, owing to the particles of quartz and undecomposed feldspar. The feldspars in the weathered zone take on whitish and chalky appearances due to the partial change to kaolin and the micas become brittle and bleached. In the upper zone these minerals are mostly decomposed into residual clay.

From the diagram we note that there is less silica and more alumina in the residual clay than in the fresh rock. A portion of the silica which

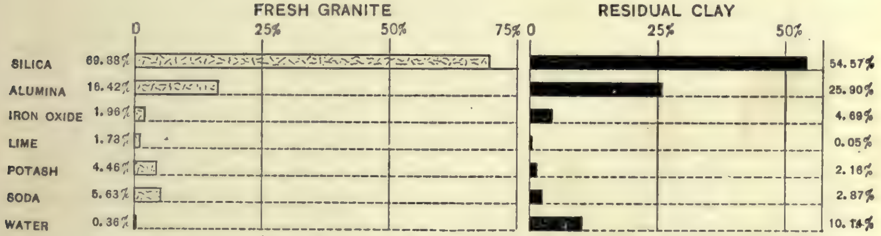


FIG. 80.—Diagram to illustrate the chemical composition of a granite and its residual clay. (Data after Watson.)

existed in the rock as quartz has, doubtless, gone into solution and been lost. The higher percentage of alumina is due in part to the fact that there is a higher percentage of clay in the residuum. In this case the iron oxides are higher in the clay than in the fresh rock for the iron-bearing minerals, mostly biotite, in the granite have decomposed in part to iron oxides which are rather insoluble and surround the sand and clay grains mostly as thin films. The lime, soda and potash are decidedly less in the clay owing to the solubility of their weathered compounds, mostly carbonates. Furthermore, some of the lime, soda and potash yet remain in the form of the original feldspars which are as yet undecomposed and remain in the clay, where they slowly decompose and yield valuable plant foods. This slow decomposition explains the "staying qualities" of most granitic soils. The marked increase in water in the clay is due to the fact that clay is a hydrated mineral, for in its formation water has united with alumina and silica to form the clay.

The mineralogical composition of the Cecil soils of North Carolina which are derived from granitic rocks is given below.[1]

| Percentage of minerals not quartz in | | Abundant minerals, not quartz, in | |
|---|---|---|---|
| Sand, per cent. | Silt, per cent. | Sand. | Silt. |
| 30 | 34 | Orthoclase, muscovite, biotite, epidote, microline. | Muscovite, biotite, orthoclase, epidote, microline. |

This soil is found mostly on the rolling surface of the Piedmont. It is thoroughly weathered and of a reddish color, especially in the subsoils. In spite of the extensive decomposition there are considerable quantities of feldspars and mica in the sand and silt. The mica is especially abundant in flakes of microscopic size in the silts, Fig. 81. These fine particles of feldspar and mica are of great value in supplying potash and lime to the soils.

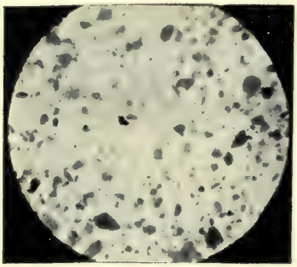

FIG. 81.—Microphotograph of the soil from igneous rocks containing biotite mica. Most of the dark minerals are biotite. N. C. (Plummer, N. C. Experiment Station.)

**Notable Regions.**—While granites have wide surface exposures in North America, the areas in the Rocky Mountain region are, for the most part, hilly and not of much agricultural value. However, the rolling Piedmont in the eastern part of the United States includes large areas of productive soils derived from granites and gneisses. Two great soil series here are largely derived from granites, the Cecil series in the southern Piedmont and the Chester in the northern Piedmont. These soils are characterized by red, heavy subsoils with angular quartz grains scattered through soil and subsoil and mica is common in the subsoils. The Durham series is siliceous and is derived from acid granites.

[1] J. K. Plummer, Journal of Agricultural Research, Vol. 5, Part 1, 1915–16, pages 569–581.

## Soils From Basic Rocks—Diorite and Basalt

**Introductory.**—It will be remembered that these rocks are more basic than the granites, that is they contain more iron, lime, soda and magnesia and less quartz. In these rocks there are relatively large amounts of hornblende, biotite, olivine and those feldspars which contain considerable lime and soda. The rocks are typically dark gray to black in color and are usually hard and heavy. Locally they are often known as " black rocks " or " greenstones." Diorite is a rather common rock in many localities, especially in the southern Piedmont and, it will be remembered, there is a very large area of basalt in the Columbia River region, Fig. 28.

**Weathering in General.**—In general, rocks high in lime, iron and soda decompose more readily than the granites, which are more siliceous, but this is, however, subject to many variations since rock structure and texture are potent factors in weathering. Then nearly all the prominent minerals in these rocks possess easy cleavages which facilitate disintegration and thereby allow free play to the agents of decomposition. Again, the dark colors of these rocks is a persistent factor favoring disintegration. It will readily be apparent that, since the feldspars ultimately weather to clay and the hornblende and allied minerals weather to clay and iron compounds, the soils derived from these rocks are clays strongly colored with the oxidized compounds of iron—heavy reddish soils with but little quartz.

**Diorites and Their Soils.**—Diorite soils are important in the southern Piedmont. They have heavy subsoils of sticky yellowish clay or clay loam with but little quartz. The subsoils pass below into weathered diorite or similar rocks.

The **chemical composition of these soils** is illustrated in Fig. 82, which shows interesting comparisons between fresh and decomposed diabase, a rock somewhat similar to diorite but more basic. The fresh rock has a coarse, granular texture with a dark-gray color and greasy luster. Feldspar, augite, and some magnetite and olivine can be recognized by the unaided eye and these minerals account for the rather high percentages of iron, lime, magnesia and soda in the fresh rock. The residuum is an orange-colored clay with most of the lime and magnesia leached out as soluble carbonates. The alumina and silica have not changed greatly since they are present in the residual clay. The very high percentage of iron in this case is due to the fact that much of the magnetite ($Fe_3O_4$) and some augite, both iron-bearing minerals, remain undecomposed as small grains. The feldspar has nearly all been changed to clay.

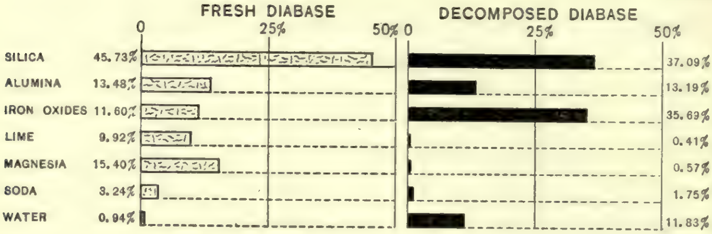


FIG. 82.—Diagram to illustrate the chemical composition of fresh and weathered diabase. (Data after Merrill.)

The following mineralogical analysis of soils from basic rocks (Iredell series) illustrates some of the features of these soils: [1]

| Minerals other than quartz in | | Abundant and Characteristic Minerals in | |
|---|---|---|---|
| Sand, per cent. | Silt, per cent. | Sand. | Silt. |
| 30 | 40 | Augite, hornblende, epidote. | Biotite, epidote, hornblende. |

This soil is derived from basic igneous and metamorphic rocks, a derivation that is evident from the high percentages of the basic iron-bearing minerals that persist in the soil. The feldspars have practically all been decomposed both in the sands and in the silts, owing in part to their comparatively easy solubility.

**Basalts and Their Soils.**—Basalts are important soil-forming rocks in some localities. The term is somewhat general; ordinary basalts are porphyritic and olivine ($(MgFe)_2SiO_4$) is a common phenocryst, but often basalts are dense and only minutely porphyritic. Many volcanic flows, both recent and ancient, are basaltic, and most active volcanoes eject basaltic lavas. Basaltic lavas are usually porous, a feature which helps in rapid weathering, and this, together with the basic composition which is favorable for weathering, causes such lavas quickly to yield productive soils. In fact, vines are often set out on recent lavas

[1] McCaughey and Fry, loc. cit.

from Vesuvius only a few years after eruptions. The basalts of the Columbia River flow, Fig. 28, are lava flows rather recent from a geological point of view. They are weathered in places to a depth of 60 or more feet to a reddish mantle rock which often yields productive soils. Basalts are often found in dikes, sills and other forms of volcanic origin.

## Obsidian Soils

These glassy rocks are not important soil makers, both because they are not of wide extent and because the soils are generally infertile. The obsidians occur in considerable areas in recent lava flows, notably in the region of the Columbia River lavas, Fig. 28. Here for the most part the obsidian areas are but little weathered, the soils are thin and the areas are almost destitute of vegetation. The obsidians are notably resistant to weathering, especially decomposition, for it is mostly by disintegration that they are changed into soils and the process is very slow. Sharp, angular sand is usually formed and this may change into soil by long-continued weathering.

## Schist Soils

Schists vary greatly in composition but in general they are basic rather than acid. They have a great variety of minerals which have

Fig. 83.—Soils mostly from mica schists, Pa. (U. S. Bureau of Soils.)

been developed by metamorphism, among them being micas, hornblende, garnet and feldspars. Talc is a frequent mineral and gives a characteristically greasy feel to many soils from schists. Mica and hornblende schists are by far the most common and are the only ones of much importance as soil makers. Like gneisses, schists often have long inclusions or " stringers " of quartz and feldspars which remain undecomposed in the soil. Schists are typically rather infirm and easily broken up and one can often pick weathered mica schists to pieces with the fingers. Naturally such rocks yield readily to disintegration and this is especially true of mica schists, which are often so thoroughly broken up that the mica flakes are carried by the streams and blown about by the winds and are known locally as " sand." Schists are usually associated with gneisses and often with slates. The mica schists, although they disintegrate very readily, do not decompose rapidly, for the mica is resistant to chemical weathering. When subject to complete weathering, schists give rise to heavy soils usually with a high content of reddish clay. The talc and very small mica grains in some schists often give a " greasy " feel to these soils.

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## INHERITED SOILS

It will be apparent that a residual soil is not derived from the underlying rock as is sometimes stated, but rather from rock which has disappeared by changing into soil and that this former rock at one time overlay the present bed rock. In other words, most residual soils have been derived from weathering of rocks which overlay the present soil and, in a sense, the soils are *inherited* from rocks which have disappeared. An exception to this inheritance occurs when rocks are newly exposed such, for example, as the soils from a recent volcanic flow when the soil is due only to the weathering of the fresh rock surface. However, the statement holds true in most cases that residual soils are derived from more or less thick rock strata which have disappeared through weathering. The term *inherited soils* is useful only when the soils have peculiarities or characteristics which are due to some formerly overlying stratum.

In humid climates at least, the residual soils are the residue of rocks the soluble portions of which have been carried away. The insoluble residue of one rock stratum sinks down to mingle with the residue of the underlying strata as the weathering goes on. It is true that some insoluble materials, especially the finer particles, are washed away, but practically all residual soils due to the weathering of considerable thicknesses of rocks contain materials from rocks that were formerly overlying.

The soils of the Bluegrass region of Kentucky have been cited as classic instances of inheritance. Within the boundary of this limestone region as a whole, comprising about 8000 square miles, where the phosphorus content of the soil is relatively high, there are three sub-areas differing among themselves in phosphorus content and in other respects, and hence also in fertility. These named in the order of the age of the formations which constitute their bedrock are: Inner Bluegrass region, Eden shale belt and Outer Bluegrass region. The first is in general the more fertile, the phosphorus content both in the soil and in the bedrock being here the highest. It comprises what to the early pioneers were known as the " fine lands of the Elkhorn district." These lands truncate the " Jessamine dome " and in consequence are bedded on a formation known as " Trenton," here highly phosphatic. The Trenton, itself, can be sub-divided into various beds, the highest of which, but one, is the most phosphatic. It has been noted that wherever the lands are bedded upon the formation next below this highly phosphatic horizon their soils possess the greatest phosphorus content. In some places here the concentration next the bedrock is so great that these layers are mined for the manufacture of commercial fertilizers. It is evident that they have " inherited " their phosphorus from the highly phosphatic bed by which they were formerly overlaid.

Miller disagrees with the view advanced by Shaler that any of the soils of the Inner Bluegrass have inherited to any extent materials derived from formations which were once as much as a thousand feet above this region, and have long since been removed. The chert in the soil, supposed by Shaler to be residual from these formations which once extended over this region at this great height, is believed by Miller to have developed in the soil from silica set free by the decay of a certain siliceous bed within the body of the Bluegrass limestone itself. In no instance does this chert contain fossils from these much higher formations long since removed from over the region.

However, near the margin of the Outer Bluegrass, the soils though formed in the main from the upper Cincinnatian lying at the top of the Ordovician, also contain siliceous geodes from the Knobstone formation (Lower Mississippian), the retreating escarpment of which known as Muldrow's Hill is in plain sight, so that the evidence is conclusive that the soils of this outer rim have received contributions from a formation only recently (in a geological sense) removed from it.

Another example of soil inheritance is shown in Fig. 85, an area in Oklahoma where the present soils are markedly influenced by formerly

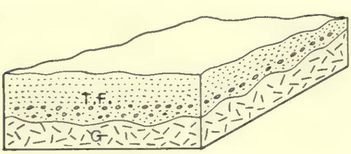


Fig. 84.

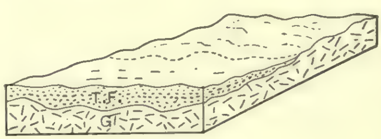


Fig. 85.

Fig. 84 shows the Tishomingo formation (*TF*) overlying granite (*G*). In Fig. 85 the Tishomingo formation has been mostly eroded with the result that inherited soils cover the upper part of the diagram, Okla. (Data from U. S. Geological Survey and U. S. Bureau of Soils.)

overlying strata. The sea advanced over the surface of the granite (*G*) and deposited the Trinity Formation (*TF*), mostly sandstone but containing layers of gravel in the lower portions. After this there was an uplift which increased the activity of the streams so that erosion has stripped away much of the Trinity Formation, again exposing the old, formerly buried granite surface in many places. As a result, some soils are derived from the old exposed granite and some from the sandy and gravelly Trinity Formation. Still other soils are inherited and include materials from both formations.

Widely distributed but disconnected areas of inherited soils occur near the junction of the Piedmont Plateau and the Coastal Plain, Fig. 86. The coastal Plain is composed largely of sand and clay, for the most part unconsolidated, and the strata dip gently away from the Piedmont Plateau. On the other hand the Piedmont Plateau is mostly underlain by hard, consolidated rocks. Formerly the Coastal Plain extended further back a considerable distance over the Piedmont Plateau but erosion has removed most of the finer Coastal Plain materials so that only some gravels and sands have remained on the Piedmont Plateau to modify its soils. A case in point is illustrated in Fig. 86.

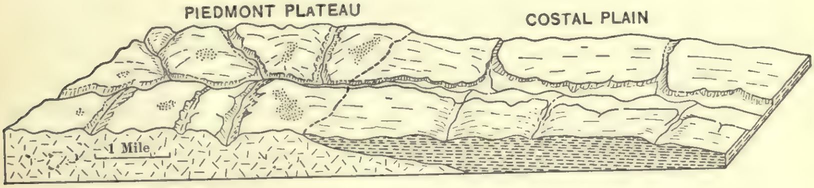


FIG. 86.—Diagram of the junction of the Coastal Plain and Piedmont Plateau. The dotted line shows the junction. The dotted areas indicate formerly overlying Coastal Plain materials which have not been entirely eroded. (Adapted from U. S. Geological Survey.)

Small patches of sand and gravelly material yet remain on the Piedmont Plateau as inheritances from the formerly overlying Coastal Plain while still larger areas contain coarse materials from formerly overlying Coastal Plain Formations. Finally there are fine examp es of soil inheritance in soil belts surrounding the eastern Ozarks, an example of which is shown in Fig. 87. The rocks here are gently dipping

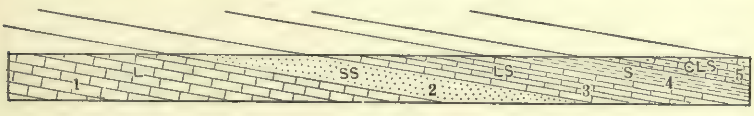


FIG. 87.—Diagram to illustrate inherited soils. The successive formations have contributed to the soils to the westward (left). (*LS*) limestone; (*SS*) sandstone; (*S*) shales; (*CLS*) cherty limestone. Section about 25 miles long. (Data from U. S. Bureau of Soils.)

and such soils often show marked inheritance. The soils in this area are practically all silt loams, but most of the soil belts show marked influences due to formerly overlying rocks. Each formation formerly extended westward at higher elevations than at present and, as a formation was worn away, its coarser and more insoluble materials sank and constitute a part of the soils now overlying rocks to the westward. Such a structure causes the different soil types to grade into each other and to resemble the soil belt on the next adjoining formation to the eastward. For example, the soil from the sandstone, (*SS*, 2) is much like the soil from the next limestone belt to the east (*LS*, 3) but the subsoil is what one would expect from the sandstone alone. Again, the insoluble cherts from the cherty limestone (*CLS*, 5) are scattered over types to the westward types which were once overlain by this formation.

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## CHAPTER V

# WIND WORK AND EOLIAN SOILS

**Introductory.**—One living in a humid climate is likely to underestimate the importance of wind work, but in dry regions, where there is an abundance of loose materials for the winds to move, the effects of winds are much in evidence. Dust storms are not uncommon even in humid regions and a strong wind may, in a few hours, carry away $\frac{1}{100}$ of an inch of soil. At this rate it would require only one hundred winds to move an inch of loose materials and only 1200 winds to move a foot, a rate that, from a geological point of view, is comparatively rapid. From the viewpoint of soils, wind work is very important in all climates, for the effects are confined to the surface of the upper mantle rock which, of course, constitutes the soil. Wind work is practically universal the world over and, furthermore, as has been noted under volcanoes, dust may be carried by upper air currents around the earth. The Sirocco, a hot, dry southerly wind in Italy, brings reddish dust from the Sahara in northern Africa, a distance of hundreds of miles, and this dust mingling with rain sometimes causes the so-called " bloody rain " of this region. Indeed, " it would, perhaps, be an exaggeration to say that every square mile of land surface contains particles of dust brought to it by the wind from every other square mile, but such a statement would probably involve much less exaggeration than might at first be supposed " (Chamberlin and Salisbury). Wind work is an example of the cumulative effectiveness of apparently insignificant agents which operate persistently and for a long time.

**Atmospheric dust** is, in large measure, due to wind work. Its universal presence is shown by a shaft of sunlight in a darkened room. The presence of air dust is also shown by melting snow which leaves a very thin layer of dust. Indeed, one of the agricultural benefits of snow is the fine dust which is left; in exceptional cases, $\frac{1}{12}$ to $\frac{1}{16}$ of an inch of dust has been left by the melting of a heavy snowfall.

## Wind Transportation

Wind transportation, like water transportation, is largely conditioned by velocity, but since air is only about $\frac{1}{813}$ as heavy as water, the striking force of winds is very much less than that of water. Whirlwinds and eddies in the air carry dust upwards and strong horizontal winds strike dust particles and project them on a journey somewhat like that of a ball from a bat. Wind load, however, is almost invariably very fine, seldom but a fraction of a millimeter (about $\frac{1}{25}$ inch) in

Fig. 88.—A stratum of white volcanic dust (pumicite) 9 feet thick lies between strata of clay about the middle of the hill. The pumicite is volcanic dust and is believed to have been transported hundreds of miles by the winds. (E. H. Barbour, Neb. Geological Survey.)

diameter. The importance of wind as compared to water transportation lies in the broad sweep of the winds which pass over hills and valleys and are but little affected by slopes. It is interesting in this connection to note that Udden estimates the transporting power of the winds over the Mississippi Basin to be something like one thousand times as great as the transporting power of the Mississippi itself. The pumicite deposits of Nebraska and adjoining states are examples of the effectiveness of wind transportation over long distances, Fig. 88. This material is very fine volcanic dust, Fig. 25, which must have been blown hundreds of miles, for there is no possible source nearer than the Rocky Mountain region to the westward.

## Dunes

are hills of sand that are moving or have been moved by the wind. Given a small obstacle like a clump of bushes or a rock, the winds are checked and some of their load is dropped and this dropped load in turn is an obstruction which leads to further deposition by the wind. Dunes move with the wind because the winds blow the sand up the windward side of the dune and the sand then drops down the leeward side as shown in Fig. 89. Thus dunes will advance over a region and often when they move over forests they leave in their wake the deadened trees which are appropriately called "tree graveyards." Dunes are often a menace to fields in their path and to roads and railroads which they sometimes obstruct. The rate of dune movement varies greatly. Most dunes move but a few inches a year, but they have been known to move 70 feet or more annually.

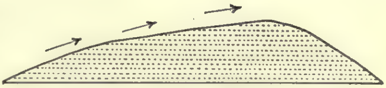

FIG. 89.—Profile of a dune. The arrows show wind directions.

Several factors affect dune formation. (1) First, of course, is an abundant supply of loose materials, usually of sand, but sometimes of silt which the wind can move. For this reason, dunes of various dimensions are often found on sandy beaches and in regions where the soils are very sandy. They are especially characteristic of arid regions where sand is easily moved. (2) Constancy of wind direction is an important factor for, while shifting winds may move materials, they do not tend to pile up dunes of notable heights. (3) Then strong winds, especially if they blow in dry seasons, are effective, other things

FIG. 90. A dune advancing on a forest, Indiana.

being equal. For instance in our arid and subarid West and Southwest, southerly winds are strong and persistent in the summer. Sand drifts accumulate on the south side of dense hedges and on the north side of fences. Dunes form in favorable localities along some valleys where sand is blown from uplands and from the valleys of rivers and lodges in a belt of dunes on the leeward of the valleys. Not all dunes are moving, especially in humid regions, where they are often covered by timber, shrubs or sod, but, with close cutting of timber, forest fires, too close pasturing or otherwise destroying the protective covering, the dunes are often again set in motion. Dunes have been successfully controlled in Europe by planting pine forests, which not only hold the dunes but afford revenue as well.

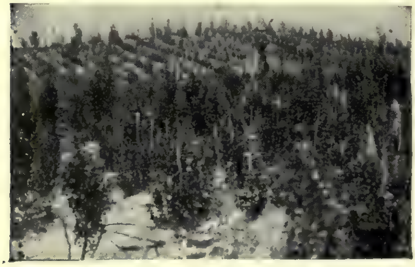

FIG. 91.—Tree planting to hold "Creeping Joe," a traveling dune, Mich. (F. H. Sanford, Michigan Agricultural College.)

## WIND ABRASION

This process is especially prominent in dry regions with high winds. In such climates the sand is largely due to disintegration and, therefore has sharp edges which are so effective in abrasion that the lower parts of telegraph poles are often worn away. Clear air, like clear water, has little abrasive power and becomes an effective abrading agent only when it is armed with sand and then it has a sand blast effect that is seen in desert erosion, Fig. 92. The effectiveness of this sand blast is often seen where windows exposed to drifting sand become translucent in a few months owing to the sand abrasion of the glass surface. Wind, as a geological agent, however, is, for the most part, important as a carrier of materials that have been comminuted by other agents, so that the load of winds is for the most part secured from rocks that have been broken up by weathering rather than by wind work.

**Soil Blowing.**—Wind work in dry regions is a factor to be reckoned with because of the "blowing" of soils by which the soil from a field may be removed during a single storm, Fig. 93. Corn rows that lie in the direction of prevailing winds in a dry region are likely to be scoured out, leaving the corn rows in relief. Sandy soils of some humid regions are also subject to blowing. Since air is so light, the winds are readily checked by obstructions such as trees and shruds, which retard the

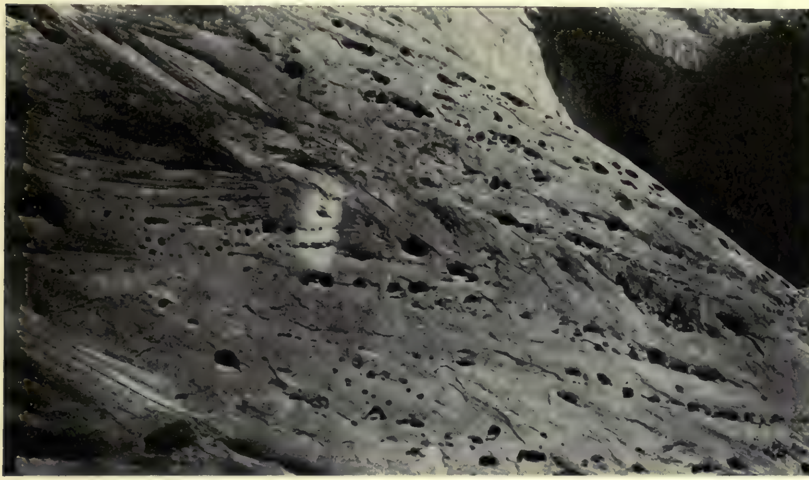

Fig. 92.—A wind-abraded rock surface, Arizona. The pits are largely due to solution. (Gregory, U. S. Geological Survey.)

Fig. 93.—"Blowing" of soil due to the destruction of protective vegetation, Michigan. (F. H. Sanford, Michigan Agricultural College.)

movements of the lower air and so protect from wind erosion; for this reason, wind breaks of trees are useful in some dry regions. Interlacing roots bind the soil particles so firmly that, so long as there is a fairly good sod or a fairly dense vegetation cover, there is little danger of soil blowing. It has been found, for example, that a rather sparse growth of certain willows will check soil blowing because these willows have long, numerous underground stems and roots. Vegetation also keeps the soil moist so that the soil grains are more or less bound by tenacious films of water. The incorporation of humus in soils also tends to check wind erosion, for humus tends to keep soils more moist.

## THE LOESS

The loess (German *lös*) is a formation which is undoubtedly due in large measure to wind work. It is a superficial deposit, very important from a viewpoint of soils both because of its wide exposure and the fertility of its soils. With the possible exception of alluvial soils, the loessial soils are probably, as a whole, the most productive soils in North America.

The loess is a fine-grained, silty material often locally called " clay," but it neither puddles nor holds water as does clay. In color it is typically brownish or yellowish, although locally it may be gray or black. The most distinctive characteristic of loess is its behavior on exposure to weathering or erosion. Where other materials, such as sand and clay, are worn to more or less gentle slopes the loess stands in nearly vertical faces, and often the vertical faces present a rudely columnar appearance as shown in Fig. 94. Road cuts in loess become small canyons as the soft material is washed away and old whiffletree marks are often preserved a dozen feet above the road; shovel marks in railroad cuts remain clear for years, Fig. 95. The cause of this peculiar characteristic is not fully understood .

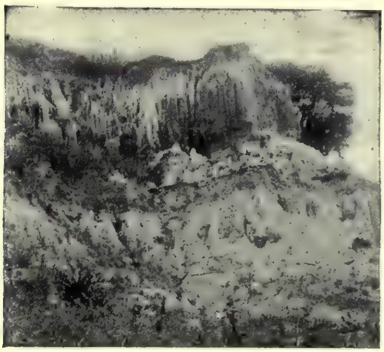

FIG. 94.—Columnar appearance of loess, La. Note the steep face of the loess and the more gentle slopes of the underlying clay.

**Mechanical Composition.**—A remarkable feature of loess is its general uniformity, especially in mechanical composition. It is invariably silty with a content of clay between 20 and 30 per cent and still less sand. It shows little or no stratification and there is but little change in vertical section. A handful of loess from Iowa, for instance, is but little different from the loess of Illinois, Louisiana or Europe. In mechanical composition, most of the loess is a silt intermediate in size between very fine sand and clay; in other words, most of the loess particles are microscopic. The fine particles are usually somewhat angular, Fig. 96. The soils are almost invariably silt loams, as is shown

FIG. 95.

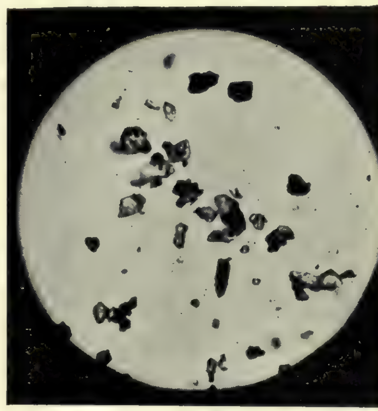

FIG. 96.

FIG. 95.—Steam shovel marks in loess about 15 years old, La.

FIG. 96.—Microphotograph of loess particles. Enlarged about 250 diameters.

by the following table, which gives composite mechanical analyses of samples from Iowa, Illinois, Wisconsin, Indiana, Missouri and Louisiana:[1]

| Gravel. | Coarse sand. | Medium sand. | Fine sand. | Very fine sand. | Silt, | Clay. |
|---|---|---|---|---|---|---|
| 0.1% | 0.6% | 0.5% | 1.4% | 9.0% | 73.7% | 14.2% |

**Mineralogical Composition.**—Chemically the loess is largely siliceous sand. Quartz sand constitutes most of the coarser materials of the loess and even the silts are largely of this material. Usually there are considerable amounts of feldspar, hornblende and other minerals

[1] For definition of soil classes, see page 29.

present in the silt. The following table shows the minerals in the sands and silts of two important loessial soils:[1]

MINERALS IN SANDS AND SILTS OF LOESSIAL SOILS

| | Minerals other than quartz in | | Abundant and characteristic Minerals in | | Less abundant Minerals in | |
|---|---|---|---|---|---|---|
| | Sand, per cent. | Silt, per cent. | Sand. | Silt. | Sand. | Silt. |
| Marshall silt loam | 12 | 15–20 | Orthoclase, plagioclase, microcline, oligoclase, andesine. | Epidote muscovite | Apatite, muscovite, hornblende, rutile, garnet, zircon, sillimanite. | Hornblende, biotite chlorite, tourmaline, orthoclase, zircon, microline, sillimanite. |
| Marion silt loam | 10–12 | 12 | Microline, hornblende, orthoclase. | Orthoclase, hornblende. | Fluorite, zircon, garnet, tourmaline, plagioclase, oligoclase, epidote. | Tourmaline, microcline, epidote, titanite, chlorite. |

The coarser particles (sand) show a relatively percentage of minerals other than quartz and both sand and silt show about one-eighth of minerals other than quartz, a proportion rather higher than in most soils. The orthoclase, microcline and micas furnish potash and the plagioclase feldspars, hornblende, epidote and garnet furnish lime. The loess is often, but not always, rich in lime carbonate, especially in the upper Mississippi Basin, where lime concretions of various shapes are common and locally characteristic of the loess. Less common but yet frequent are iron and manganese concretions.

## Origin of Loess

**The Problem Stated.**—The loess is a superficial formation mantling many other formations. It is relatively thin, seldom exceeding 50 feet in thickness and usually much thinner. Several facts must be explained in order to account for the loess. (1) It is a material that has been

[1] McCaughey and Frye, op. cit.

transported for a considerable distance and often deposited on materials that are quite different from the loess. (2) Furthermore, the loess is often resting on a buried topography that has been roughened or smoothed before the deposition of the loess. (3) Then the loess is irregular in its distribution; in places it is thickest on divides and again the thickest loess is found in valleys. (4) Fossils are scanty as a rule and consist largely of land or fresh-water pond snails; in other words, the fossils are mainly land forms.

**The Possible Agents.**—Obviously the loess, being a transported material, must have been carried by ice, water or wind. The absence of all characteristic glacial features at once excludes ice as the transporting agent. Water currents, as we see later, deposit their materials in layers, say, for example, in layers of sandy materials interspersed between layers of clay. In contrast to such an arrangement is the characteristic uniformity of loess for scores of miles, a uniformity which would be practically impossible for water currents to produce unless the loess were accumulated in lakes where currents are few and weak. Lakes presuppose basins inclosed by higher lands and such are rarely, if ever, found in connection with the loess. One other explanation might be possible; if a stream should carry only fine loessial materials, its deposits would necessarily be loess. Such a load would be almost impossible except for a small stream and, moreover, much of the loess lies too high for streams to have deposited it.

The explanation of most loess as a *wind* or *eolian* deposit presents the fewest difficulties and is generally accepted by geologists, except possibly for relatively small areas. As we have seen, the winds carry only fine materials and, therefore, their deposits would lack well-marked stratification and would be uniform, because wind load is mostly composed of fine materials.

Figs. 97 and 170 show the close association of the large loess areas with glacial materials. Glaciation will be taken up in some detail in later chapters and at this point it is sufficient to state that not long ago, geologically speaking, much of North America was invaded by huge glaciers from the north. The glaciers swept up soil, boulders and many kinds of materials and deposited them when the ice melted back. The ice also ground up much of the coarse material in transit and usually left a mixture of rocks and clay called "boulder clay." Such a surface of more or less incoherent materials exposed by the recession of the glaciers would furnish fine materials for the winds to sweep up, especially if the materials were dry. Furthermore the vegetation presumably was scanty and winds would have a free sweep and the soils, not being held by sod and roots, would be easily swept away. The primary source of most loess in North America and Europe is, therefore, thought to be glacial materials. On the other hand, in China the fine desert debris, broken up by weathering, furnishes much of the loessial materials.

The two tongues of loess along the Mississippi River, Fig. 98, apparently have a somewhat different origin. Of these, the eastern belt is much the wider and more continuous with an average width of perhaps forty miles; the western belt is much narrower and less continuous, being rather a series of areas than a continuous belt, Fig. 98. These belts do not extend up tributaries as would be expected if they were of alluvial origin. It is believed that the Mississippi loess is also indirectly connected with the glacial period in that it is probably largely derived from glacial deposits. At times when the glaciers were melting, vast floods must have come down the Mississippi Valley carrying and depositing the fine-grained glacial materials. As the waters subsided when the ice melting was less active, widely extended mud flats must have been exposed to winds which caught up the dust and deposited it on the uplands adjacent to the river on both sides, the westerly winds depositing the eastern belt and the easterly winds the western belt.


FIG. 98.—Loess areas in Louisiana and Mississippi.

The problem is only partially solved, however, when only the agents of transportation and deposition, together with the primary sources of the loess, are considered. What conditions would favor the accumulation of this fine, dust-like material? Obviously a dry climate would be a favorable condition and at present loess is being deposited by winds in some dry areas in China; it is not, however, at present being deposited in notable quantities in North America. It is believed on good evidence that a dry climate prevailed at times during the glacial period so that, although the winds would not have to be necessarily stronger or more persistent than at present, the conditions for their getting and carrying dust loads were especially favorable. The angular shapes of the fine loess particles, Fig. 96, are shapes that are most easily carried by the winds for their irregularities cause the dust particles to settle more slowly than smoother particles.

**Cooperating Agents.**—While wind appears to be the main depositing agent of loess, other agents are always contributory. Weathering breaks up rocks so that winds can carry the fine particles. Glaciers also grind up rock and water from glaciers assorts the particles, both processes furnishing fine materials. Streams are very important in that they place their fine-grained deposits so that they are available for eolian action. A close association of stream and wind work in China has been described by Willis.[1] Here, dust from interior deserts has been swept into the rivers, carried down to the lowlands and there deposited by the rivers as sandy loess. From these lowlands, the winds have swept up the loess and spread it over the uplands. Probably many areas of valley loess in North America have had a somewhat similar origin.

## Loessial Soils

These soils are usually productive. They are readily cultivated and are especially important wheat and corn soils in the upper Mississippi Basin. In general these soils usually contain ample potash and lime and many have fair amounts of phosphoric acid. The table below gives a general idea of the plant food in these soils:

PLANT FOODS IN POUNDS PER ACRE (ABOUT 7 INCHES) OF LOESSIAL SOILS[1]

| | Total nitrogen. | Total phosphorus. | Total potash. |
|---|---|---|---|
| Illinois [1] | 3,796 | 1,140 | 33,223 |
| Nebraska [2] | 3,700 | 1,007 | 24,110 |
| Iowa [3] | 4,197 | 1,422 | 32,518 |
| Louisiana [4] | 2,540 | 850 | 22,084 |

[1] Bull. 123, University of Illinois Agricultural Experiment Station, by Cyril G. Hopkins and James S. Pettit, 1908 (some non-loessial soils are included).

[2] The Loess Soils of Nebraska, by F. J. Alway, W. L. Blish, R. M. Isham, Soil Science, Vol. 1, 1916.

[3] Bull. 150, Iowa Agricultural Experiment Station, by Percy E. Brown, 1914.

[4] Data from Louisiana State Experiment Station, I. Selecter, Soil Chemist.

The northern loess has been comparatively little leached and is somewhat high in potash and lime. On the other hand, the southern loess materials have probably been transported by the Mississippi and

[1] Researches in China by Bailey Willis, Vol. 1, Carnegie Institution.

thus leached during transit and, moreover, they have been subjected to rather heavy rainfall so that they are somewhat lower in potash and lime. The potash of the loess is mainly in the form of feldspars, which furnish slowly available supplies of potash.

The structure and mechanical composition of loessial soils are especially favorable to the movements of soil moisture. The soils are usually porous enough to allow a fairly ready downward movement of gravitational water, and on the other hand they are fairly retentive of moisture and allow the upward movement of capillary moisture in dry weather.

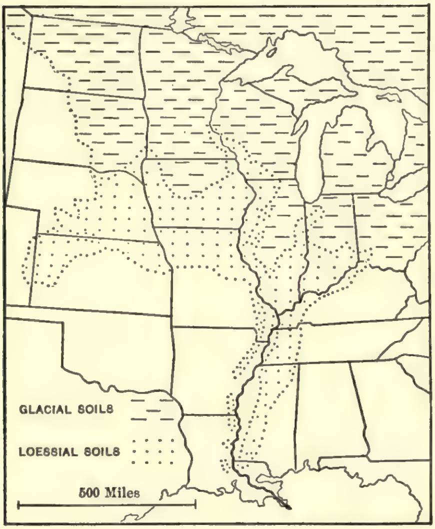

Fig. 97.—The principal areas of loessial soils in North America. (After Coffey, U. S. Bureau of Soils.)

The wide distribution of loessial soils in the United States is indicated in Fig. 97, where it is seen that the great areas are in Illinois, Iowa and Nebraska. It is a formation distinctively confined to the Mississippi Basin with the principal areas in the upper Basin and with long narrow belts along the Mississippi from the mouth of the Ohio nearly to the mouth of the Mississippi. The obvious relation to the Mississippi and to other rivers and the appearance of the loess in the bluffs have given the local name "Bluff Formation" to the loess and "bluff soils" to the soils. The loess has a wide distribution in China and considerable areas are found in Europe.

Three main soils have been described in North America. The Marshall silt loam is a dark-colored loessial prairie soil, one of the most important corn soils of the Middle West. The Memphis silt loam is typically a brownish soil which is derived from the loess that borders both sides of the Mississippi south of the Ohio. The Miami silt loam is a light brown soil which covers much of southern Illinois and Indiana.

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## CHAPTER VI

# GROUND WATER

**Ground water,** as the name implies, is the water contained in the earth as distinguished from the water that runs on the surface. Its presence is evidenced by the thousands of wells, springs and seepages by which the ground water reaches the surface. The ultimate source of most of the ground water is the rainfall, but the ground water at a given place is not necessarily derived from local rainfall because there is some movement of ground water from place to place. For example, the artesian well water of the High Plains comes from the Rocky Mountain area hundreds of miles to the westward. Much of the ground water ultimately returns to the surface by springs and seepages, some enters the sea by underground courses, some is drawn upward by capillary movement, some is held in the pores of rocks and a very small portion enters into chemical combination to form hydrated minerals and so for the time becomes fixed.

The total amount of ground water is necessarily undetermined. Most observed rocks are porous and contain some water, but it is believed that at a depth of several miles the rocks are compacted by the pressure of the overlying materials so that there is little or no space for the accumulation and movement of ground water. To give an idea of the enormous quantity of ground water it may be stated that all estimates agree that, if the ground water were brought to the surface, the lands would be covered to the depth of scores of feet. The water moves for the most part through the rock pores and naturally, in fine-grained rocks like shales, the movement is very slow. Sandstones and conglomerates, because of their greater pore spaces, furnish the greatest storage capacity and permit the most rapid movement. These rocks, therefore, contain the great stores of artesian water.

### The Water Table

The *water table* is the upper level of the ground water or, in other words, the level below which the earth's crust is more or less saturated with ground water; the water table is never a definite surface like that of a lake but rather an indefinite zone. In swamps it may practically coincide with the earth's surface while in arid regions it may be hundreds of feet underground. That the depth of the ground water varies, even in small distances, is shown when a "dug" well strikes water at a given depth and another well near by reaches water at a different depth. When shallow wells "go dry" the water table has sunk beneath the bottoms of the wells. The depth of the water table below the surface varies with many factors including the amount and character of the rainfall, the kinds of materials such as sand, clay, etc., and the porosity of the materials. In general it is not level. It stands higher in some materials than in others and, moreover, it usually corresponds roughly to the surface above as shown in Fig. 99, although it does not rise and fall as sharply as the topography. Again the level of the water table varies locally; for example, a heavy rainfall will raise it while a long dry spell will depress it. It is hardly necessary to state that the depth of the water table is of great economic importance as the depth conditions to some extent the depth of wells. The depth of the water table is also important from an agricultural standpoint. In very dry seasons it descends so far that the roots of deep-rooting plants cannot be supplied with moisture and, again, in wet seasons or in swampy regions it may rise so high that the root zone of plants is saturated and many plants are injured in consequence.

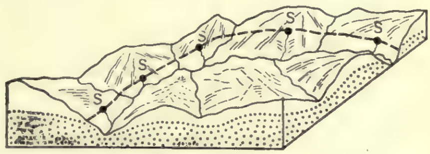


Fig. 99.—Diagram to show a common relation between topography and ground water (dotted). Springs ($S$) occur where the water table is reached in valleys.

There is naturally no sharp distinction between soil water and ground water although, of course, the former is included in the latter. Soil water is an extremely small portion of the ground water but, from an agricultural point of view, it is an extremely important part. We shall first consider the general features of ground water and then apply the principles to soil water.

## Ground Water Movements

These movements are, in general, very slow as compared with the movements of surface waters. First there is the downward gravitational movement by which the water descends to the water table. This movement is approximately in a vertical direction although, owing to differences in rocks, the movements may be in a combination of downward and lateral directions. Then there is the "underflow," which is common along streams that are underlain by gravels and sands. For example, some portions of the Arkansas River may be dry but beneath the surface in the sands and gravels there is always a slow movement down stream. In some rocks, especially limestones, there are large openings through which the water movement is relatively rapid and this is also true of movements in crevices and joints, but for most of the ground-water movement, the term percolation would be most appropriate.

## Work of Ground Water

This may be considered under two heads, the *mechanical* and the *chemical* work. Because of the slow movement of ground water its mechanical work is but of slight importance except in soils, and this topic will be considered under soil water. The chemical work of ground water may be considered under two heads, *solution* and *deposition.* These and other topics related to ground water have been considered under weathering, but the importance of the process will justify some repetition here.

**Solution.**—The universality of this process is proved by the fact that practically no stream or well waters are free from materials in solution. Lime compounds, as a rule, are the most common materials dissolved in natural waters, a fact which is proved by the common lime coatings in kettles and boilers. Solution is promoted by several factors. (1) Practically all ground water contains carbonic acid and probably other acids in solution so that the soluble minerals in rocks and soils are in time dissolved. (2) It is a matter of common observation that the solvent action of water is greatly increased by heat. Some deep mineral deposits are thought first to have been dissolved by hot waters, and subsequently deposited, and some hot springs are now depositing not only soluble minerals but silica, which is ordinarily insoluble in water, Fig. 100. (3) An increase in pressure increases the solvent power of water and, of course, (4) a decrease in pressure lessens the ability of water to hold substances in solution. (5) Finally, other things being equal, it is evident that time is an important factor in solution. The longer ground water is in contact with a substance the greater the solvent action, and for this reason slowly moving ground water is much more effective, volume for volume, than the waters of streams.

FIG. 100.—Calcareous tufa, a hot spring deposit, Cal. (U. S. Geological Survey.)

**Caverns and Sink Holes.**—Perhaps the most striking features due to the work of solution are the caverns which are so frequent and large in many limestone regions because limestones, as has been seen, are especially soluble in ground water. The water percolating along joints or bedding planes dissolves the rock and constantly enlarges its channels until a system of galleries and rooms is formed, often at different levels. Shaler estimates that, in the great Mammoth Cave of Kentucky, there are probably more than 200 miles of fairly continuous openings which, at times, enlarge into spacious chambers and again are so narrow that one has difficulty in passing through them. Another common accompaniment of caverns and other solution work are *sink holes*, round depressions in the bottoms of which there are usually passageways by which surface waters escape downwards. Such a sink hole is shown in Fig. 101. These underground passageways often become obstructed, either accidentally or purposely, and the sink holes become ponds which are often used as stock ponds. Where there are many sink holes they produce a peculiar characteristic "billowy" topography.

FIG. 101.—A sink hole, Tennessee. (U. S. Bureau of Soils.)

### Deposition by Ground Water

This process is the factor to which we are indebted for most of the important deposits of iron, zinc, lead, copper and some gold and silver deposits. The phenomena of deposition by deep-seated waters are very difficult to explain completely but it may be said that, whenever the ground water becomes saturated with a given mineral, that mineral will be deposited. Probably first in importance among the factors of deposition is a (1) decrease in temperature by which the water loses its solvent powers. (2) A decrease in pressure also lowers the solvent power of water, as when deep waters rise into regions of less pressure. (3) Finally there are chemical exchanges between different solutions, as when scrap iron is thrown into water containing copper and the copper slowly replaces the iron. An interesting example of *substitution* is when wood and other organic materials change to stone, a process termed *petrefaction.* The particles of wood decay and are replaced by silica or other substances which are in solution in the ground water.

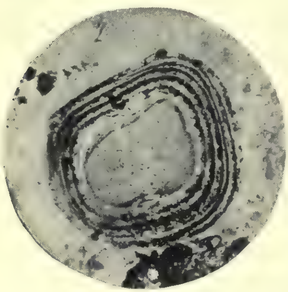

FIG. 102.—Microphotograph of chert. Ground water has deposited the minute layers. (U. S. Geological Survey.)

**Mineral veins** are common occurrences in workable ores. The ground water passing through crevices or zones of weakness deposits various minerals often in roughly arranged bands. Usually the water deposits not only valuable minerals but also other minerals which are regarded as impurities, of which the principal ones are quartz and calcite. Many veins are composed entirely of these minerals or other minerals of little or no commercial value.

## SOIL WATER

This is the ground water of the soil, constituting, of course, the upper part of the great mass of ground water. The processes are almost alike in the soil water and in the deeper ground water, but not all the factors are equally important. (1) In general, soil water contains more oxygen and carbon dioxide, (2) it has less pressure, (3) is subject to more active evaporation and (4) the downward movement of the soil water is in general much faster than in the deeper ground water. (5) Furthermore, the mechanical work of soil water is of great agricultural importance while that of the deep ground water is almost negligible. Hydration, oxidation, and solution vary with so many factors that comparisons of their effectiveness in the soil water and deeper ground water are hardly possible.

**Movements.**—The familiar *downward* or *gravitational water* results from the sinking of rainfall into the ground. The rapidity of downward movement is obviously affected by the porosity of the soil, for it is a matter of common observation that rain will sink into sandy soils more rapidly than into clay or silty soils and more rapidly into silt loams than into clays. A sudden, brief heavy rain will penetrate less than the same amount of water falling for a longer time, since it takes time for water to expel the soil air and work its way downward among the soil particles. The downward movement is hastened by soil cracks, roots, root paths and the holes of burrowing animals.

**Capillary Water.**—The rise of oil in a lamp wick and the fact that a towel hanging over the side of a basin will in time drain the basin are familiar llustrations of capillarity. Similar capillary movements occur in soils and are important. This movement takes place in all directions, the direction of movement being from areas of more soil moisture to those of less soil moisture. Capillarity thus aids the downward movement and promotes drainage. The upward movement brings moisture to soil and subsoil and is beneficial to crops in dry weather. When the capillary moisture reaches the surface, it is, of course, evaporated; soil mulches are produced to check this evaporation.

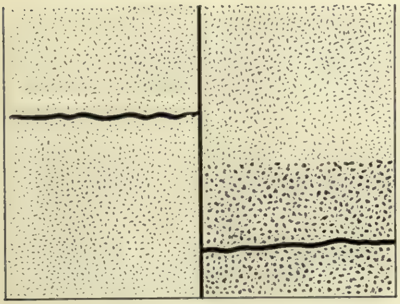

Fig. 103.—The water table (heavy line) in the soil to the right is depressed by coarse gravel. (After Hilgard.)

All soils do not favor capillary movement equally well. Fine-textured soils, like very fine sands, sandy loams, loams and some silt loams favor a rapid movement of capillary water. Coarse sandy soils and very heavy clay soils are less favorable for this movement. In general, a texture between a coarse sand and a heavy clay is favorable for capillarity or, in other words, small soil grains, unless they are very small, are most favorable to capillary action. Sometimes a coarse gravel below the subsoil will cut off capillary moisture and cause a "bald spot" in a dry season, Fig. 103. While the upward movement of capillary water has been emphasized, it should be remembered that it moves in all directions. The movement is very slow and inconspicuous, but its importance is shown by King's estimate that, under most favorable conditions, if the movement were continuous and the supply sufficient, over 63 inches of water could be delivered to the earth's surface in a year, an amount greater than the annual rainfall in most regions.

**Mechanical Work of Soil Water.**—In humid regions the subsoils are usually heavier in texture than the soils. A sandy soil is likely to have a sandy loam or a sandy clay subsoil; a sandy loam often has a subsoil of sandy clay and a silt loam is often underlain by a silty clay loam or silty clay. Even a clay soil usually has a heavier subsoil, although commonly there is not so much difference between soil and subsoil in clay soils. The main reason for this difference between soil and subsoil in humid regions is that the gravitational water in its relatively rapid descent carries the finer materials such as silt and clay which are found in nearly all soils into the subsoils. Here the downward movement is checked, the carrying power of the descending ground water is diminished and the finer particles are deposited in the pores between the larger particles of the subsoil. Fig. 104 illustrates the occurrences on subsoils in Kansas and Louisiana where both a heavy soil and a light soil are underlain by heavier subsoils. Naturally in arid regions there is a weak gravitational movement and the subsoils are not so well developed so that there is little difference between soil and subsoil.

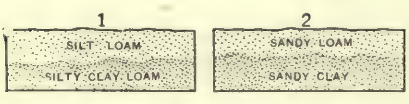


Fig. 104.—Soil and subsoil in (1) loess; (2) in sandy loam.

**Chemical Work and Soil Water.**—This work has been in part discussed under the topic of "Weathering."

*Oxidation.*—Descending gravitational water naturally carries considerable oxygen and many porous soils are well oxidized and have reddish or brownish colors due to coatings of iron oxides on the soil grains. Subsoils show much variation in oxidation. Porous subsoils are likely to be reddish and well oxidized; heavy silty clay soils may be underlain by subsoils that show the reddish and brownish colors due to oxidation in their upper portions, while the lower subsoil may be oxidized in spots, and still further down the deep subsoil may be bluish or grayish and practically unoxidized. In many cases red or brown subsoils are favorable indications when these colors are due to active oxidation since they indicate good aeration. Here as elsewhere hydration commonly accompanies oxidation, and limonite, the hydrated iron ($Fe_2O_3 \cdot 3H_2O$), is often apparent in soils because of its yellowish colors.

*Carbonation* is especially active in soils, both because the supply of carbon dioxide is derived from the decaying vegetable matter in soils, and the rains carry large amounts from the air into the soils. Carbonic acid is a weak acid and does not work actively, but in humid climates an enormous amount is carried down by gravitational water and this quantity, in some degree, compensates for the weakness of the acid because of its dilution. The carbonates are in general fairly soluble, especially if there is an excess of carbonic acid in the solution. The soluble lime and magnesian carbonates are common in many soils, and the iron carbonates, while less soluble, are also found in many soil solutions.

*Solution* is an important and widespread work of soil waters which always contain some acids. The gravitational water moves relatively rapidly through the soil after each wetting of the surface and generally less rapidly through the subsoil, so that the more soluble minerals are leached from the soil and to a less extent from the subsoil. This long-continued leaching is especially effective on many sandy soils. It is often shown in sags where the water accumulates and the underlying soil is gray from leaching. The red soils of the Orangeburg series in the southern Coastal Plain usually have a few inches of gray leached soils overlying brilliant red subsoils. The capillary water, bulk for bulk, has a greater solvent effect than the gravitational water, for it moves much more slowly and, therefore, is longer in contact with the soil particles. Moreover, when exposed to the action of capillary water, each soil particle is closely and tenaciously surrounded by a film of water which dissolves soluble materials from the surface. This water film is very thin and a small amount of water covers many square feet of soil particles, so that total solvent effect of this inconspicuous solvent is, therefore, very important.

*Deposition.*—A casual examination of many soils and subsoils will show evidences of deposition by soil water in the shape of red, brown, black or white concretions ("gravel") or in some cases in the formation of "hardpan." Furthermore, a microscopic examination is likely to disclose concretions in almost any soil. These concretions, although often called gravel, are not to be confused with actual gravels which have been deposited by water or weathered from rocks.

The gravitational water doubtless deposits some of its dissolved minerals in the subsoil especially if, as is often the case, the subsoil is fine textured and so retards the descent of the soil solution. But it is probable that most of the dissolved materials in the ground water are carried below the subsoil and some are there deposited at varying depths. On the other hand, the ascending capillary water must deposit much of dissolved materials in the subsoils for at least two reasons. As the ascending capillary water reaches the subsoil, the pressure is lessened and the water evaporates. Furthermore it will be remembered that, with release in pressure, the ground water tends to deposit its solution load. Lime carbonate (calcite) in the soil affords an example. The carbonic acid in the ground water changes the lime carbonate into the soluble bicarbonate according to a reaction which may be represented by the following equation:

| Calcite | and | Carbon dioxide | and | Water | produce | Lime bicarbonate |
|---|---|---|---|---|---|---|
| $CaCO_3$ | + | $CO_2$ | + | $H_2O$ | = | $Ca(HCO_3)_2$ |

The lime bicarbonate is somewhat unstable and, when warmed or the pressure released, it easily reverts to the relatively insoluble lime carbonate. Now, when the soil solution reaches a more porous material or enters cavities, a portion of the carbon dioxide escapes and the lime carbonate is deposited as concretions or as a coating on the soil grains, or as an irregular stratum or hardpan and since the subsoil is usually less porous than the soil, it follows that deposits are often found near the merging of soil and subsoil as shown in Fig. 105.

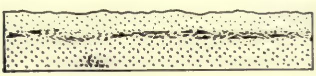

Fig. 105.—Diagram to illustrate the frequent occurrence of hardpan and concretions between soil and subsoil.

Oxidation usually promotes deposition in soils because the oxides formed are relatively insoluble and the same is true of the common hydrates (combinations with water) in soils. The iron oxide, hematite ($Fe_2O_2$) and the hydrated iron oxide, limonite ($Fe_2O_3 \cdot 3H_2O$), are very common in soils, as reddish and yellowish coating on soil grains and as concretions. Black concretions, composed mostly of iron and manganese oxides, are not uncommon, especially in heavy soils. Sometimes these concretions are so numerous as to form a hardpan or a kind of bog iron ore or "ironstone" and the same feature is often seen in "lime hardpans." It is probable that many of these concretions were carried up as soluble compounds by capillary water to the soil and upper subsoil where oxygen is plentiful and there changed to less soluble oxides and deposited. However, there are many complex reactions in the soil solution which are as yet imperfectly understood and which offer a valuable and fruitful field for further investigation. Recent studies have indicated that it is probable that concretions have practical interest in that many of them seem to contain compounds of phosphorus which are so slowly soluble that little, if any, of their phosphoric acid is available for crops. Finally, it should not be forgotten that roots bring up soluble materials to the soil and subsoil and some of these materials are again put into circulation in gravitational and capillary waters.

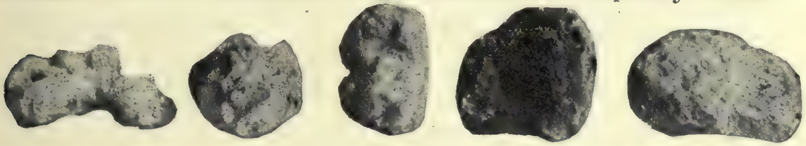

Fig. 106.—Soil concretions. The three on the left are of lime, on the right, mostly of iron compounds.

**Hardpan** is an indefinite term usually denoting a relatively hard or impervious layer beneath the soil or in the subsoil. In regions of scanty rainfall hardpan is very commonly of lime or magnesium carbonate where it may be due to scanty gravitational water which carries the materials downward to certain depths where they are deposited, or it may be due to rising capillary water. In many cases the hardpan is probably due to both processes. When irrigation water is used too plentifully both of the above-mentioned processes are intensified and it not infrequently happens that hardpans form beneath irrigated orchards and cause them to be abandoned. In humid regions hardpans often form in the subsoil where the fine materials of the subsoil are cemented by lime carbonate or by iron oxides.

**"Alkali."**—One of the most important agricultural problems in dry countries is the deposition of alkali in soils, the "rise of the sub" as it is often termed. "Alkali" is a general term including several soluble salts, among them being sodium sulphate ($Na_2SO_4$), NaCl ("salt"), magnesium sulphate ($MgSO_4$) and sodium carbonate ($Na_2CO_3$) or "black alkali." The black alkali is the most dreaded; it may be white in color, and its dark color is due to its action on humus. Very often the so-called alkali includes many or all of these compounds, which are injurious to crops.

The presence of these salts is a notable work of rising capillary water. The soils and subsoils are but little leached and there is, therefore, an abundance of soluble minerals. Much of the gravitational water descends for a relatively short distance and much of it rises by capillarity, a rise doubtless accelerated by the rapid evaporation at the surface of the soil. When the capillary water reaches the soil or the surface it evaporates and, of course, leaves its dissolved compounds. It is a common experience that, when an excess of irrigation water is applied, the water table rises towards the surface, more capillary water therefore passes through the soils and the lands are temporarily ruined

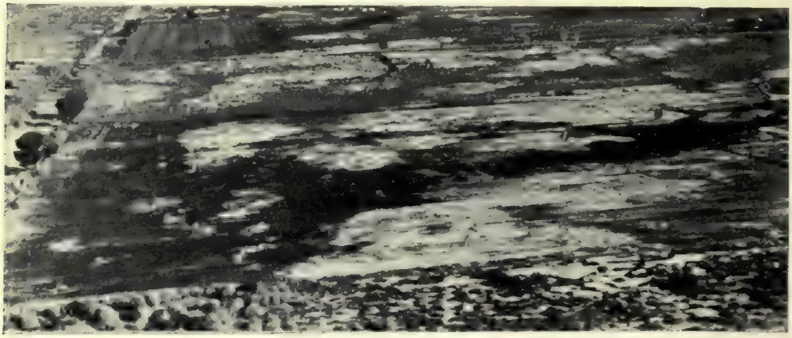

Fig. 107.—Patches of alkali in alfalfa. The soil was formerly productive, but alkali has been brought up by capillary water derived from irrigation water, Arizona. (U. S. Bureau of Soils.)

for most crops. However, when heavy applications of water are made and this water is removed by subsoil drainage, the salts may be washed from the soils. Probably many soils in humid regions would become alkaline if the rainfall were to become scanty for long periods.

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## WELLS AND SPRINGS

**Springs** occur when the ground water escapes at the surface; the flow may be strong or merely a seepage. Most commonly springs occur in valleys where the water table readily reaches the surface, Fig. 99. There is usually a relatively impervious layer like clay or a close-grained rock which is overlain by porous materials like sand. The water sinking through the sand flows along the clay to the point of escape at the spring. Sandstone is so porous that springs are common in a "sandstone country." Limestone is likely to contain openings along which water flows sometimes as an underground stream which, when it emerges, makes a large spring. Some springs flow along joints or faults until they emerge at the surface.

**Wells.**—Ordinary shallow wells are sunk until they reach the water table. Sometimes wells are dug or driven into rock until a supply of "living water" is found in a porous stratum usually of sand or sandstone. Artesian wells are those from which water flows or in which water rises from the bottom. In other words, these wells tap an underground supply which is under "head," that is, the source of the water is higher than the bottom of the well. In general there are two usual necessary conditions for artesian wells. There must be a porous stratum to hold the water and allow it to flow and this porous stratum must be enclosed by relatively impervious materials to confine the water. Again the stratum must be dipping so as to furnish a "head" for the water. The outcrop of the water-bearing stratum is termed the *catchment area* because the rain and snow falling here furnish the supply which enters the stratum and is available for artesian wells. Other things being equal, the lower the dip the larger the catchment area, as is illustrated in Fig. 51.

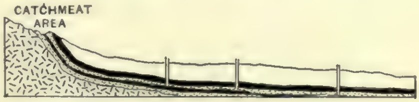


FIG. 108.—Generalized diagram showing the catchment area east of the Rocky Mountains from which the sandstones (dotted) carry the underground water beneath the Plains.

Artesian wells have become very important sources of water supply, both for cities and for rural districts. It is extremely fortunate that our dry plains in the West are underlain by structure and materials that are favorable for artesian wells. Such structure and arrangement are seen in Fig. 108, where the important water-bearing Dakota sandstone rises steeply near the eastern front of the Rocky

Mountains and there forms an extensive catchment area. The rain and snow in this catchment area sink into the porous sandstones and slowly flow underneath the plains to the eastward. The structure of the Coastal Plain in the United States is also very favorable for artesian water, which is being extensively utilized, although most of this area has an ample rainfall. A little reflection will show that a frequently stated assertion that "the underground waters are practically inexhaustible" is untenable. At most no more water can enter the rocks than falls on the catchment area and not all of this water is available for artesian wells.

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## CHAPTER VII

## STREAMS AND THEIR WORK: ALLUVIAL SOILS

In practically all habitable regions the topography is being shaped by stream work and, indeed, this must have been true since the beginning of geological time. Most hills and mountains, nearly all valleys and in fact most surface features show in some measure the work of streams. Enormous areas of productive soils are due to stream work.

**Sources of Streams.**—Rainfall is the primary source of all streams, although there are apparent exceptions where a river like the Colorado flows through an arid region, but, in this instance, the river's head waters are in a more humid region. Not all the rain escapes through streams, for a portion sinks into the ground (the cut-off), another portion runs off mostly in streams (the run-off), while still another portion escapes by evaporation. It has been estimated that approximately one-fourth the rainfall of the world escapes by run-off and the removal of forests and the improvement of drainage by tile and ditches is artificially increasing the run-off. The ground water also contributes to streams when it sinks into the ground and emerges as springs or as the less noticeable seepages, but the amount of ground-water contribution to streams is likely to be underestimated because it is inconspicuous. Streams are permanent when fed by ground water and intermittent when fed only by run-off; they are often permanent in their lower courses where the water table (page 120) is reached and intermittent above this point.

**Stream Organization.**—On a level slope with an equal precipitation over the surface, the run-off would consist of a sheet of water covering the entire surface, a condition of *sheet flow* found in a few localities. But such conditions are rare since the precipitation is unlikely to be uniform, even in small areas, and natural drainage lines are likely to be found even on apparently level surfaces. Hence it is the most of the run-off is accomplished in various degrees of efficiency by streams. The primary purposes of streams from a geological point of view are (1) promoting the run-off and (2) carrying the land debris to the sea.

**The velocity** of a stream depends (1) mainly on the slope of its bed, and since most streams have steeper slopes in their upper portions, it is there that they are usually swiftest. (2) The velocity also varies according to the volume; streams flow fastest in times of high water. (3) Somewhat less obvious is the fact that stream velocity varies with the amount of load that a stream is carrying. If a quantity of loose material like sand or sawdust, for example, is thrown into a stream, the current becomes slower. This last factor, while not easily observed, is believed to be important in changing some streams from depositing to carrying streams and vice versa. (4) Other things being equal, a stream flows faster in a straight channel than in a crooked one and (5) in a smooth than in a rugged one. (6) Finally a stream flows less rapidly at the top and the bottom because of the friction of the air and the bottom, respectively, and (7) less rapidly at the margins because the shallow water there also meets with more friction.

## STREAM WORK

### Stream Erosion

**Introductory.**—Streams are incessantly wearing down the land and transporting the debris to the sea. Small streams during and after rains become muddy because of their traveling load of fine sand, silt and clay, and large rivers are nearly always muddy. There is also a considerable invisible load that all streams carry in solution.

#### Corrosion

This is the solution work of streams; it is sometimes called chemical denudation. Corrosion is closely connected with weathering and ground-water work, since the ground water in its slow journey leaches out soluble materials, some of which are carried to streams. Because of this it is clear that much of the invisible load is brought to streams by ground water rather than by the rapidly moving run-off water. A stream corrodes its channel to a very slight extent and its fine load also gives up some soluble materials, but these are minor sources of supply. Obviously the amount carried in solution by streams is closely related to the rocks of the stream basin. Streams draining a limestone basin will ordinarily carry much more soluble materials than those from a sandstone region and, other things being equal, streams from regions covered with materials ground up by glaciers will contain considerable soluble material. It is estimated that the Mississippi River is lowering its basin one foot in 25,000 years by corrosion. Murray has estimated that nineteen principal rivers of the world carry the following amounts in solution:

| Constituents. | Tons in cubic mile. |
|---|---|
| Calcium carbonate ($CaCO_3$) | 326,710 |
| Magnesium carbonate ($MgCO_3$) | 112,870 |
| Calcium phosphate ($Ca_3P_2O_8$) | 2,913 |
| Calcium sulphate ($CaSO_4$) | 34,301 |
| Sodium sulphate ($Na_2SO_4$) | 31,805 |
| Potassium sulphate ($K_2SO_4$) | 20,358 |
| Sodium nitrate ($NaNO_3$) | 26,800 |
| Sodium chloride ($NaCl$) | 16,657 |
| Lithium chloride ($LiCl$) | 2,462 |
| Ammonium chloride ($NH_4Cl$) | 1,030 |
| Silica ($SiO_2$) | 74,577 |
| Ferric oxide ($Fe_2O_3$) | 13,006 |
| Alumina ($Al_2O_3$) | 14,315 |
| Manganese oxide ($Mn_2O_3$) | 5,703 |

It is at once evident that lime and magnesium carbonates constitute the bulk of the dissolved materials and the lime phosphate and sulphate of potash show the continued loss of valuable plant food. In the humid regions the decaying vegetation supplies carbonic acid and the soluble compounds are, therefore, largely carbonates, but in arid regions, where this agent is for the most part subordinate, the more common compounds are sulphates and chlorides. Thus many rivers in the western Mississippi Basin which flow from semi-arid through humid regions show an increase in carbonates in solution from source to mouth and an increase in chlorides and sulphates in the opposite direction.

## Corrasion

This term is applied to the wear and tear of the stream load upon its channel and of the particles of the load upon themselves. Clear water in itself has little power to corrade and it is only when the current is supplied with rock as tools that corrasion is effective. The Niagara and St. Lawrence, both clear rivers, show the inefficiency of clear water in corrasion. At the very brink of the American Falls where the current is swift there are delicate thread-like plants (algae) which would shortly be scoured away were there any considerable quantities of sand or pebbles carried; the upper St. Lawrence has not yet removed the delicate glacial scratches on the rock of its channel.

The tools by which a stream can corrade are the rocks, pebbles, sand and silt carried by the stream which, striking upon the bottom and colliding with each other, grind and chip off fragments of the load. The efficiency of corrasion varies primarily with the stream's velocity, but the size, shape and hardness of the materials carried are important factors. Under the rolling, grinding and colliding of the particles the stream load becomes rounded, a characteristic shape of stream pebbles. Aside from active factors, the rate of corrasion is obviously influenced by the resistance of the underlying rock. The Colorado River

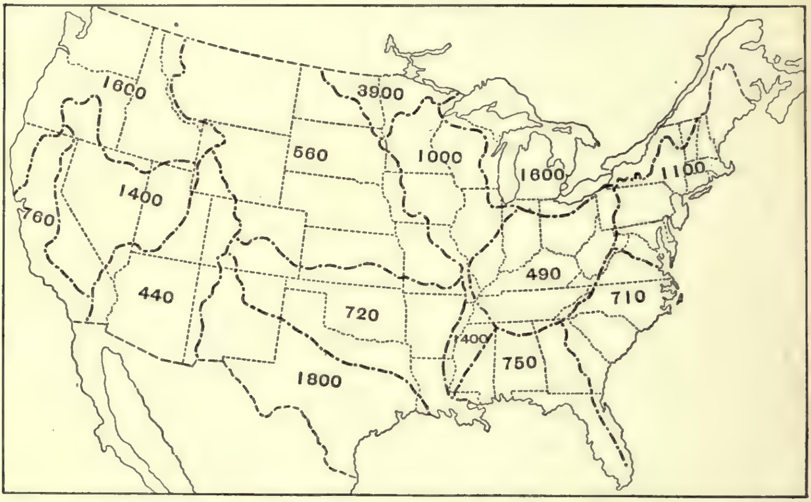


FIG. 109.—The figures in the different districts show the estimated number of years required for the land to be reduced one inch by erosion. For example, the Ga., S. C., N. C., Va. area will be reduced one inch in 710 years. (After National Conservation Commission.)

furnishes an example of rapid corrasion owing to its volume, high velocity and ample supply of rock tools by which, in a short time, geologically speaking, it has cut the famous Colorado Canyon. A corrading river "may be compared to a sinuous, flexible and endless file, ever moving forward in one direction . . . and rasping away the country rock beneath" (Pirsson and Schuchert). The combined work of corrosion and corrasion in lowering the land is shown in Fig. 109.

### The Development of Valleys and Divides

It has been noted before that practically all the run-off from rainfall is accomplished through streams. The depression in which a stream flows is its *valley,* while the area drained by a stream and its tributaries is its *basin.* The growth of a valley can perhaps be best understood by taking as an example a small valley or gully. A valley begins where, because of natural drainage lines, weak materials or perhaps an especially heavy rainfall, there is started a line of drainage. The running stream soon cuts a trench with steep slopes at the head and the trench is widened by the inflow of water at the sides. The valley grows at its head because the slopes here are steeper and the water runs faster and, therefore, corrades rapidly. Such erosion at the heads of valleys is known as *head erosion.* In time tributaries will develop and neighboring streams will cut valleys so that there will be an advancing zone of head erosion in many valleys. The combined head erosion in the valleys sometimes produces a united series of valley head slopes so as to form a fairly continuous steep slope or *escarpment.*

Fig. 110 shows such an escarpment in the Texas Panhandle, which is of considerable extent. The eastward flowing streams to the right (east) are extending their valleys westward by head erosion and invading the plain which formerly extended far to the eastward. Thus there are three belts, the level, uneroded plain at the left, the middle hilly zone of head erosion or "brakes" with an escarpment and the rolling eroded prairies to the east, each having different soils and drainage. The escarpment, so to speak, is invading the plain to the west and leaving in its wake the rolling prairies.

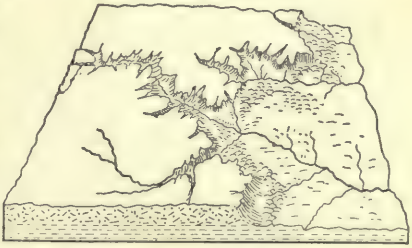

Fig. 110.—Head erosion of several streams producing an escarpment, Texas. (Data after Gould, U. S. Geological Survey.)

Another extremely interesting example of head erosion on a large scale is seen in the western High Plains of the western Mississippi Basin, Fig. 111. This area, the soils of which are composed of loose unconsolidated materials, shows two distinctive regions, one flat and uneroded and the other, eroded and rolling, while between these areas is a more or less well-marked escarpment. It will be seen that the smooth area roughly coincides with the region with dry climate and the rolling area, with the region with humid climate. The rolling area is well covered with a tenacious sod which, to a considerable degree, affords protection from erosion, "not because it resists the work of well-developed drainage but because it prevents the initiation of drainage" (Johnson). On the other hand, the streams flowing eastward have pushed back their headwaters into the dry country and are pushing the escarpment westward where the scanty bunch grass of the dry country affords but little protection against erosion.

A valley seldom is cut straight unless it is guided by some fairly straight and weak stratum as in Fig. 58, but, otherwise, the valleys tend to form a network of tributaries much like the branches of a tree. The first type is likely to be found in regions where the rocks are folded or tilted. The factor of weathering in the *widening* of valleys is often unappreciated. A stream itself cuts but little more than the stream width, but, as the stream cuts its valley, the processes of weathering on the valley sides weaken the rocks and cause them to fall and the rain wash carries the debris into the stream. As a consequence practically all valleys are flaring toward the top. Even the Colorado Canyon has a flaring cross-section, although it is very young and it has been cut in resistant rocks and the weathering in that region is comparatively slow.

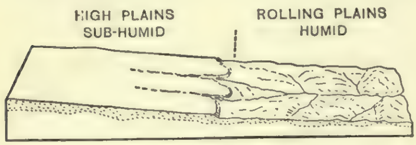


FIG. 111.—Diagram to illustrate the subhumid High Plains, the humid Rolling Plains and the dividing escarpment. (Modified from Johnson.)

**A divide,** as the name implies, is a line between two streams where the rainfall separates, a portion flowing from the divide into each stream. A divide may be sharp or indistinct and flat, high or low. Divides are sharpened by the widening of valleys or by the headward extension of streams. As valleys are widened and the tributaries push their heads away from the main streams, the divides become narrower. Many high and rugged divides constitute mountains, a good example of which is the Blue Ridge Mountains of North Carolina.

## Incised Meanders

Few streams are straight but most flow in more or less well-marked curves or *meanders* which are cut into the underlying rock and become winding trenches or *incised* or *entrenched* meanders as they are variously called. Incised meanders are important agents in widening valleys and their work will, therefore, be considered in some detail.

When a stream flows in a meander it does not cut equally on both sides, but it cuts more on the outside of the meander, for here is the fastest current. This process, continued for a long time, will result in a stream's widening its valley and eventually wearing away the protecting spurs as shown in Fig. 112. Finally, the valley is widened with perhaps here and there a remnant of a spur that once projected far into the valley. The flat bottom of the valley is an alluvial plain.

Looking again at the diagram, Fig. 112, in *A* the stream is actively cutting and, therefore, is termed a *degrading* stream. In *B*, *C*, and *D* the stream is neither actively cutting or depositing and is just able to carry its load so it is termed a *graded* stream. When a stream is actively building it is termed an *aggrading* stream.

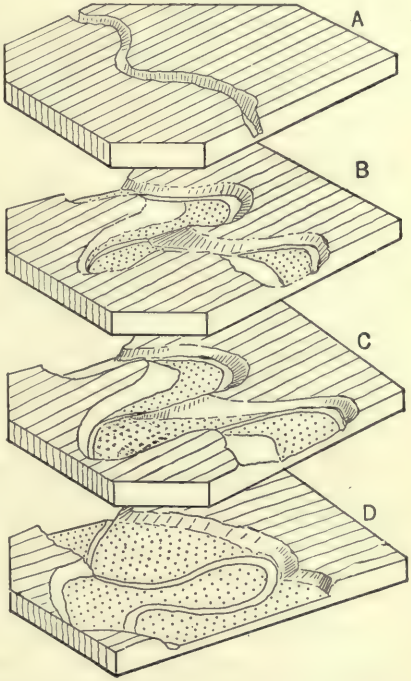


Fig. 112.—Stages in the formation of incised meanders. (Davis.)

While the soils that are typically associated with incised meanders are not extensive, yet they are important locally and merit some consideration. An example of an incised meander of the Ohio River and its associated soils is shown in Fig. 113. (*A*) represents an early stage of the meander where the river is cutting most on the left-hand bluffs. Now turning to Fig. 114, which represents a small portion of (*A*) in Fig. 113 we note that the stream cuts both vertically and laterally and, as a result, its downward cutting will be a combination of these two movements as shown by the arrows. Two characteristic slopes will result from this double cutting, one a steep slope at the left and the other a gentle slope at the right. The stream swinging outward keeps the left slope steep, while on the right slope the stream "slips off," so to speak. In other words, the stream has traveled down or "slipped off" the gentle slope and some successive positions of the stream are shown at *S*, *S*, *S*.

Now turning to (*B*) of Fig. 113, we see that the river has slipped off its long slope and is undercutting at the left. Another feature here is the level alluvial plain which is appearing at the foot of the slip-off slopes. The river has become graded, that is, it has ceased cutting vertically and is widening its valley only by lateral cutting. In (*C*) a

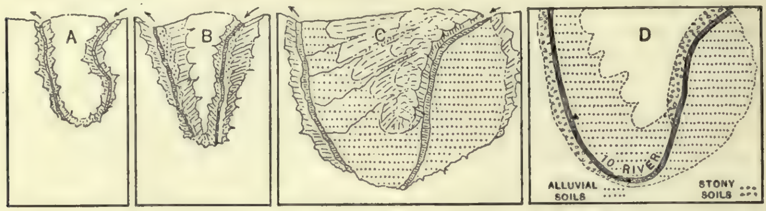


FIG. 113.—Diagrams to illustrate the formation of an incised meander and its associated soils.

later stage is represented which has been sketched from the combined characteristics of several meanders. The river is widening its valley on the left and eroding the projecting spur on its right side. It has moved laterally so far that a wide expanse of level alluvial land has been developed. Fig. (*D*) shows the characteristic soils of an incised meander. Where the river is still cutting laterally the slopes are kept steep with the result that head erosion is so active that the finer soil particles are swept away and the soils are, therefore, stony.

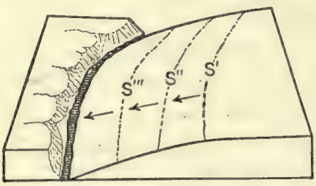


FIG. 114.—To illustrate the "slipping off" of an incised meander.

The strips of alluvial lands follow the river as it advances by lateral cutting. In some valleys one can look up stream and see a succession of smooth slip-off slopes often in cultivation while, looking in the opposite direction the rugged cliffs, due to undercutting, are in view.

## Soil Erosion

The principles concerning the development of shallow valleys and their associated divides have important applications in soil erosion, a very important agricultural problem in many places. All soils, except those on flat surfaces, are subject to some erosion, but, under favorable circumstances, the ratio of soil washing above is about balanced by the formation of soil below. *Sheet washing* occurs where practically no gullies are formed and the surface soil sometimes to a depth of an inch or more is carried away by a sheet of water during a heavy rain. The more noticeable type is "gully washing" where gullies form and sometimes grow for several yards during one rainfall. Both processes usually go on together, but sheet washing is usually not noticed because it does not notably alter the surface. "Gully washing," on the other hand, tends to render the land too rough for cultivation.

**Factors.**—The factors contributing to soil erosion are many. (1) Perhaps the most striking cause, because the results are so soon evident, is the removal of forests, Fig. 115. So long as the interlacing tree roots hold the soil and the accumulated muck and leaves absorb the rainfall and retard the run-off, there is little soil erosion even in forests where the slopes are steep and other conditions are favorable. The cutting of forests on mountain slopes has ruined thousands of acres for all practical purposes. This is unfortunately well shown in many parts of the Appalachians, but the classical example is seen in the Karst region of southwestern Austria. Here, in Roman times, was a heavily forested hilly region but, with the reckless deforestation, the hills were swept bare of soil and to-day most of the Karst is practically a desert. (2) Somewhat the same result follows the loss of a protective sod cover. In many regions of somewhat scanty rainfall and steep slopes, unwise plowing and too close grazing have destroyed the sod and made conditions favorable for soil erosion. (3) An obvious factor favoring soil erosion is steep slopes which make for rapid run-off and therefore greater corrasion. (4) Soil texture is important. A clay or silt soil absorbs water slowly so that the run-off is high while sandy soils absorb water rapidly and only heavy, prolonged rains will soak the soil so that it is notably subject to erosion. Furthermore, fine-grained soils are more easily carried away. (5) Unwise plowing and cultivating up and down hill are responsible for much sheet erosion and gullying. Shallow plowing by failing to provide loosened soil to soak up rainfall is also a fruitful cause of soil erosion. (6) A cultivation which

Fig. 115.—Destruction of the woodland without adequate reforestation has caused gullying. (U. S. Forest Service.)

depletes soil of its humus renders erosion more probable, since humus absorbs water and thereby decreases the run-off.

**Remedies for soil erosion** in part suggest themselves and grow out of the principles of valley making. Rainfall cannot be controlled nor can the soils be materially changed, so the best remedy is prevention—not to allow the head erosion to start. A *sod* is the best protection and sod on hill pastures should not be killed by too close grazing, but *cover crops* will protect the soil fairly well where there is no sod. *Deep plowing* allows the soil to absorb more water and so tends to reduce the run-off. Plenty of *organic matter* in the soil will absorb water, reduce the run-off and tend to bind the soil; this fact explains why old soils from which organic matter has been removed will wash worse than fresh soils. *Contour plowing* will allow cultivation because the contour furrows tend to retard the wash and prevent the formation of gullies.

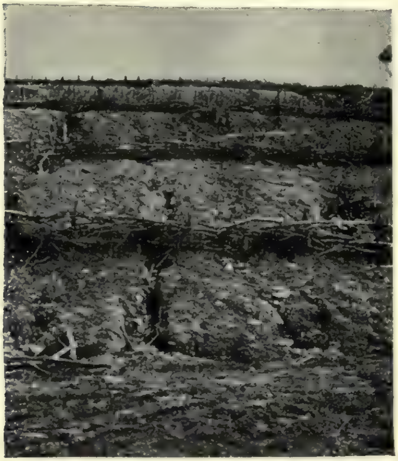

FIG. 116.—Checking of soil erosion by brush dams. (U. S. Geological Survey.)

When small valleys have started it is very important to check them early for, once started, they become deeper in the lower portions, thus increasing the slopes and making cumulative conditions favorable for growth. With the growth of such valleys, not only is the surface rendered too rough for cultivation, but soil and mantle rock are swept onto productive soils and they are made useless. Moreover, the deepening of gullies lowers the water table over adjacent areas, thus making the crops sensitive to droughts. By depositing straw, brush or other litter at the head of gullies, the head slopes and, therefore, the head erosion are decreased and, moreover, the rains sink into the loose materials thereby decreasing the run-off. If land values are high enough to warrant the expense, dams are sometimes run across valleys, sediment collects behind them and the gullies in time become nearly filled. Terraces, Fig. 117, have long been used in with valuable lands; they reduce the slope and thereby lessen the run-off and corrasion.

**Bad land topography** is due to excessive gullying, Fig. 118. It occurs most typically in portions of western Nebraska, Wyoming and the Dakotas where incoherent materials, scanty soil cover and torrential rainfall are favoring conditions. Such areas are chiefly valuable for grazing, but excessive grazing by reducing the cover will aid in the development of this topography. Extensive bad land areas have been

FIG. 117.—Terraces in Central China. The terraces both reduce erosion and aid in making the steep hill sides available for cropping. (Willis, Smithsonian Institution.)

produced in the loose materials of the Lafayette Formation in some of the Southern states by neglect of the soil cover.

## STREAM TRANSPORTATION

**Factors.**—The familiar fact that streams carry materials, or *load* as it is called, has been noted under the topic of corrasion. It is a matter of common observation that streams in high water and with consequent greater *velocity* can carry larger and heavier masses than the same streams at low water with slower current. The carrying power of streams increases very rapidly with the velocity for, if a stream's velocity is doubled, the carrying power is increased 64 times or, in other words, the transporting power of a current varies as the sixth power of the velocity. With this in mind one can understand how a small stream in flood can transport even large boulders. The efficiency of velocity in stream transportation is illustrated by the jetties which were built at one of the mouths of the Mississippi River. In order to overcome the tendency of the river to deposit its sediment and obstruct the channel, these embankments or jetties were built, one on either side, to confine the river, make it flow faster and thereby keep the channel

FIG. 118.—"Bad Land" topography, Neb. (U. S. Geological Survey; from Forest Physiography by Isaiah Bowman, Wiley & Sons, Inc.)

clear. Most streams are swiftest in their upper courses and the coarsest load is usually found here.

Other factors in stream transportation are the *size, weight and shape* of the materials making the load. For example, a stream might not be able to move a stone weighing a pound, but if the stone is broken into small fragments the stream might easily carry them away, because the total surface against which the currents could strike would be enormously increased. In other words, the larger the surface of a particle, the more easily it may be moved, other things being equal. Thus it is clear why the bulk of stream loads is composed of sand, silt and clay, which, though they may be very small, present large surfaces in proportion to their weight. The following table gives an idea of the transporting power of bottom currents in rivers.[1]

| Velocity of current. | Size of materials carried. |
|---|---|
| 3 inches per second, about $\frac{1}{6}$ mile per hour......... | Fine clay and silt. |
| 6 inches per second, about $\frac{1}{3}$ mile per hour......... | Fine sand |
| 2 feet per second, about $1\frac{1}{3}$ miles per hour......... | Pebbles 1 inch in diameter |
| 4 feet per second, about $2\frac{3}{4}$ miles per hour......... | Pebbles 4 inches in diameter |

**The Stream Load in Transit.**—The stream load is moved in two ways. The heavier, coarser sand and gravel are rolled and pushed along the bottom, while much of the fine load, like the fine sand, silt and clay is carried in suspension. The first method is characteristic of swift streams like those in mountains; slower streams carry much of their loads in suspension somewhat as dust is carried in the air. The ability of running water to carry materials heavier than itself is due mainly to three factors: (1) The impact of the moving water against a particle hurls it on a journey somewhat as a ball is projected from a bat. (2) When rocks are immersed in water, they suffer an apparent loss of about one-third of their weight, a principle which aids a stream in carrying its fine load in suspension. (3) Very small particles, once they are suspended in water, sink very slowly owing to friction and, therefore, remain suspended even without the aid of currents. A glass of river water will often not become clear for weeks. From this it should not be thought that particles remain indefinitely suspended; rather they journey by long or short leaps with rests between the journeys. Much of the load is moved in floods and rests at ordinary stages, and the load as a whole travels much more slowly than the water.

Furthermore there are numerous upward currents, the larger of which show as "boilings," which carry materials upward in the stream. Then it must be understood that a stream is not a single current, but is composed of many currents, slanting, vertical, even backwards, and these keep the water agitated so that fine materials do not readily sink.

The load of rivers is largely derived from their smaller tributaries, although small amounts may be picked up from the channels, and the amount of the load is obviously dependent on the materials of the channel and basin—whether they are of resistant rock or of unconsol-

[1] I. C. Russell, Rivers of North America, page 18.

idated materials. Sheet wash, soil creep and slumping down the sides of small rill valleys furnish load to the small streams which they transfer to the larger streams. Furthermore it must be remembered that, because a stream is competent to carry a given load, it may not actually carry that load. The stream can carry only the sediment that is brought to it. Mountain streams of high velocity are often clear because the rocky slopes do not furnish sediment that the streams could carry and even a muddy river may not be loaded to its capacity because the load is so fine that the stream can easily carry it. The following estimates are interesting in comparing different rivers:[1]

DRAINAGE AND SEDIMENT OF LARGE RIVERS

| Rivers. | Drainage area in square miles. | Average annual discharge of water in cu. ft. per second. | Sediment. | | |
|---|---|---|---|---|---|
| | | | Total annual tons. | Ratio of sediment to water by weight. | Height in feet of column, one square mile base. |
| Mississippi | 1,244,000 | 610,000 | 406,250,000 | 1 to 1,500 | 241.4 |
| Potomac | 11,043 | 20,160 | 5,557,250 | 1 to 3,575 | 4.0 |
| Rio Grande | 30,000 | 1,700 | 3,830,000 | 1 to 291 | 2.8 |
| Po | 27,100 | 62,200 | 67,000,000 | 1 to 900 | 59.0 |
| Danube | 320,300 | 315,200 | 108,000,000 | 1 to 2,880 | 93.2 |
| Nile | 1,100,000 | 113,000 | 54,000,000 | 1 to 2,050 | 38.8 |
| Irawaddy | 125,000 | 475,000 | 291,430,000 | 1 to 1,610 | 209.0 |

While the Mississippi carries more sediment than any of the others, yet its load (ratio of sediment to water) is less than several others, the Potomac for instance. The Irawaddy River with a much smaller basin carries a load that will compare with that of the Mississippi doubtless because of the heavy rainfall in the basin of the former river.

**Abrasion of the Load in Transit.**—In large rivers the finer load is found in the lower reaches and, in general, most streams show an increase in the size of particles carried as one goes up stream. In the first place, the currents in the lower parts of rivers are usually weaker and less variable and can transport only fine materials like fine sand, silt and clay. Then, in a long river, the particles of the load have been exposed to the corrasion that accompanies stream transportation and thus have been worn to smaller dimensions by their journey. This

[1] Babb, quoted by Russell, page 74.

is well shown in the following table made by Hochenburger as the result of studies made of the Mar River in Europe:[1]

| Distance carried. | Average size of fragments. |
|---|---|
| At Gratz | 224 cu. cm. |
| 5.68 miles below | 184 cu. cm. |
| 14.76 miles below | 132 cu. cm. |
| 24.42 miles below | 117 cu. cm. |
| 31.81 miles below | 81 cu. cm. |
| 40.33 miles below | 60 cu. cm. |
| 57 36 miles below | 33 cu. cm. |
| 68.16 miles below | 21 cu. cm. |

In a journey of about seventy miles the fragments have been abraded to about one-tenth their former size. This, of course, does not apply to all streams, but the table illustrates the comminution of load with its journey down stream. The same author gives the following table to show the resistance to corrasion of different rocks in the same river; the figures give the distance in miles each rock travels before becoming thoroughly broken into very small fragments:

| | |
|---|---|
| Rhaetic sandstone | 8.52 miles |
| Clay slate | 23.85 miles |
| Orthoceras limestone | 36.35 miles |
| Granular limestone | 48.28 miles |
| Granite | 157.90 miles |

Another point of great agricultural interest is the fact that, as the particles in the stream's load become smaller, they suffer less abrasion in transit mainly because the blows that they strike against each other and against the stream channel become lighter as the weights of the particles decrease. As a result the weaker but important minerals such as feldspar and apatite are carried for long distances and deposited as silt and clay in particles so small that they the more readily give up their plant food to roots; even a mineral so apparently frail as mica is carried long distances and is a not uncommon soil mineral in alluvial soils. This principle is illustrated in Fig. 119, which shows that most sand grains, easily visible to the unaided eye, are rounded by their journey, but that most of the small microscopic grains are angular.

## Stream Deposits. Alluviation

Stream deposition is the converse of stream transportation and therefore anything that lessens a stream's carrying power tends to pro-

[1] Quoted by Grabeau, Principles of Stratigraphy.

mote deposition. The process of stream deposition is sometimes termed *alluviation,* and the results, *alluvial deposits.* This process produces alluvial soils which are important in extent, productiveness and value.

## Factors

**Diminished Velocity.**—Since the carrying power of streams increases very rapidly with increasing velocity, it follows that a reduction of

FIG. 119.—Fine river sediments. On the left are grains of rounded sand, magnified; the grains are about $\frac{1}{25}$ of an inch in diameter. On the right are minute grains of silt, much magnified; the grains are about $\frac{1}{500}$ of an inch in diameter. The smaller grains are much less abraded than the larger grains.

carrying power will accompany lessening velocity. For example, a stream that is just able to carry coarse sand will drop that portion of its load when the current is slightly lessened. It will be remembered that a stream is a complex of currents, fast and slow, so that one place it may be carrying, and elsewhere, depositing sediment. Not only so, but even the same current may simultaneously deposit its coarse load and carry its fine load. Moreover, when a stream drops its heavy load, some of its energy is released and it may be able to take up and carry more fine materials if they are available, thereby effecting an *exchange of load.*

**Diminished Volume.**—We have seen that volume directly affects the carrying power of streams. Most streams have one or more high-water stages during which more and coarser sediments are carried and deposited, thus producing a succession of different layers or *strata* so that stream deposits are commonly *stratified.* The Nile is a famous example of a depositing river. During the rainy season it acquires at its headwaters a large volume by which it is able to carry its fine load for hundreds of miles and finally deposits the sediment along its lower course. Some rivers rise in a humid region and flow for a part of their courses through a dry region, and here they lose much of their volume through seepage and evaporation. As a result of the diminished volume the stream drops much of its load in its channel and flows in small streamlets through masses of its deposits. Such streams are termed *braided streams* because of their characteristic appearance. The volume of streams is greater in their lower courses but their velocity is usually less because the slope is low. Other things being equal, a rising stream will deposit relatively coarse sediments which will be followed by finer sediments as the stream subsides.

**The load itself** is an important factor in stream deposition. Obviously a lightly loaded stream cannot deposit thick sediment. The fineness and weight of the load will determine how far the load can be carried. Streams often become overloaded locally, an instance of which is seen where tributaries bring more sediment than the main stream can transport. For example, some of the rapids in the Colorado River are explained by the fact that a tributary brings a load of boulders which the main stream cannot readily carry. From these varying factors, sometimes co-operating and sometimes antagonistic but always varying, we have the marked variations in alluvial deposits. Some alluvial soils are extremely variable, while other single types cover large areas, but have frequent minor variations, and the same is true of all sedimentary deposits and rocks.

# CHAPTER VIII

## CLASSES OF ALLUVIAL DEPOSITS

For convenience it is customary to classify stream deposits as follows: *stream channel deposits; flood plains or alluvial plains; terraces; deltas; alluvial fans.*

### Alluvial Deposits in Channels

Even rocky channels usually contain some sediment. Many streams flowing in narrow valleys have thrown down some of their loads and partly filled their valleys, and this is especially true of streams flowing from regions covered with glaciers which give the streams so heavy a load that much of it is deposited in the valleys which are often deeply filled. Channel deposits are often very heterogeneous, varying both vertically and laterally, as shown in Fig. 120. Such variations are due to the highly complex and varying stream currents each capable of carrying different loads.

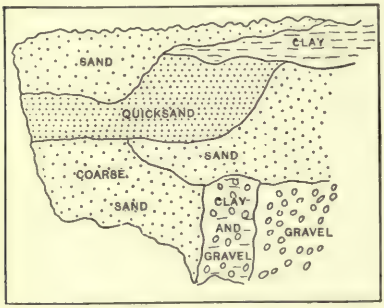

Fig. 120.—Section of Missouri River deposits showing varying character of the sediments. (After Todd, U.S. Geological Survey.)

*Bars* and *islands* are often built in heavily loaded streams. The lodging of a tree, for example, will often create an obstruction back of which deposition may occur and the materials already deposited create a still greater obstacle and further the process. Such a deposit may remain under water as a bar or it may be built to the flood surface and remain as an island when the water is lowered. The surface is soon covered with vegetation, which itself retards the velocity of the water and promotes the growth of the island. Such islands are usually more or less temporary, many being soon eroded and some being transferred down stream.

An illustration of the latter case is seen in Fig. 121. Holmes Island in the lower Missouri River moved several miles down stream in fifty-five years (1820–1875). The river impinging against the upper part of the island wore it away while in the more quiet waters below the island, sediment was deposited. By 1875 the river had shifted its course entirely away from the island.

## Flood Plains

Flood plains, as the name implies, are plains that are built by streams mainly during high water. They are known variously as "alluvial plains," "river bottoms," "first bottoms," etc. Flood-plain soils are proverbially fertile and their wide extent of available land makes them the most important alluvial deposit from an agricultural point of view.

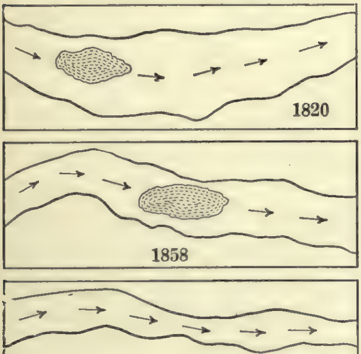


Fig. 121.—Diagram to show the down-stream movement of an alluvial island (dotted), Mo.

**Origin.**—When a stream is located in a level-bottomed valley which is at times overflowed, the conditions are favorable for building a flood plain. A stream at high water spreads over a valley and deposits sediment, usually but a very small fraction of an inch in thickness, but these deposits continued for a long time result in the building of an alluvial plain. As a stream overflows, its waters are spread over larger areas and the friction is increased with a resulting lessening of velocity It has been noted that streams are usually slower near the margin and the spreading of flood waters over a plain virtually extends the slower margin waters. Moreover, a stream in flood usually is more heavily laden with sediment, and this factor in connection with the decreased velocity contributes to the building ability of aggrading streams. Finally there is nearly always more or less vegetation on a flood plain and this favors deposition because it lessens the velocity.

**Natural Levee (Front Lands) and Back Lands.**—The velocity of an overflowing stream is not uniformly checked over the entire overflowed area and the first and most marked checking occurs near the stream. Here, as the stream loses its velocity and its carrying power, the coarser and heavier sediment is dropped and, in addition, some of the fine sediment is also deposited. The waters farther from the stream have less velocity (1) because they are spreading over larger areas and thus meeting with greater resistance and, moreover, (2) the slopes at a distance from the stream are more gentle and thus cause slower currents; these slower currents carry and deposit only finer materials and also relatively small amounts of sediment. (3) Furthermore, there is often back water which extends back from overflowed areas further down stream and checks the current. Indeed, at the beginning of floods the back water may, for a time, flow in a direction opposite to that of the main stream.

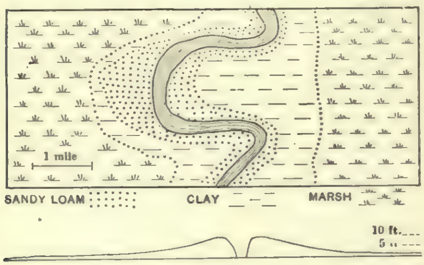


Fig. 122.—Map of a portion of the Mississippi flood plain (above). Below is a profile taken across the center of the map. (Data from U. S. Bureau of Soils.)

Since at high water the greatest deposition occurs near the stream, it naturally follows that the land here is higher. The higher land near the stream is called the *natural levee* or often locally *front land,* while the lower land farther back is usually termed the *back land,* Fig. 122. The natural levees are low ridges seldom over a few feet

Fig. 123.—The level lower Mississippi flood plain looking toward the river. Windrowed sugar cane in the foreground., La.

high above the back land toward which they descend with a slope so gradual that the region appears flat, Fig. 123. During high water the natural levees often stand out as long low islands with the river on one side and, on the other side, the flood water covering the back lands. Usually the natural levee is so high that tributaries cannot enter directly, but flow for considerable distances parallel to the main stream. The Yazoo River, for example, flows about two hundred miles along the Mississippi before it can enter, Fig. 136.

**Soils of Flood Plains.**—Not only is the land usually higher near the river, but there is typically a marked difference in the soils of the front and back lands, differences in composition, texture and drainage. The soils on the front lands are of relatively coarse texture. They are usually termed "sandy" although they may be silts; however, they nearly always contain more sand than the back land soils, hence the

Fig. 124.—The "American Bottoms." Part of the Mississippi flood plain, Illinois. (U. S. Bureau of Soils.)

common name. The coarse-textured soils of the front lands usually grade imperceptibly into the finer soils of the back lands where the prevalent types are silts and clays. In this connection, it is perhaps worth while to think of the ideal case of a river carrying a load of sand, silt and clay and overflowing the flood plain with a velocity that uniformly decreases from the stream to the limits of the back lands. Under such conditions there would be successive belts from the stream back of sands, sandy loams, loams, silt loams, silts, silty clay loams, clay loams and clays. While such an ideal arrangement is never found, yet not infrequently four or five belts of these soil types are found on the broad flood plains of the lower Mississippi and other large rivers. The changes in the overflowing currents produce many variations in the ideal arrangement. An actual arrangement of soils on the lower Mississippi is shown in Fig. 125, which shows about 16 miles of flood plain. The Yazoo fine sandy loam (*YS*) and the Yazoo loam (*YL*) are front land soils with considerable sand. The Wabash clay (*WC*) and the Sharkey clay (*SC*) are back-land soils, the former having been deposited by somewhat swifter currents than the latter. The Wabash clay is seen fringing a small stream in a wide expanse of Sharkey clay. The following table gives the mechanical analyses of these different types and, while not typical of all sections, it shows the change from relatively coarse particles to finer particles from the river to the back lands:[1]

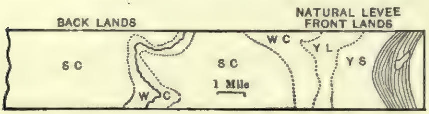

Fig. 125.—Map of soil types on a part of the Mississippi flood plain. (U. S. Bureau of soils.)

| | Coarse sand. | Medium sand. | Fine Sand. | Very fine sand. | Silt. | Clay. |
|---|---|---|---|---|---|---|
| Yazoo fine sandy loam (*YS*) | 0.6 | 0.4 | 4.0 | 35.4 | 52.6 | 7.1 |
| Yazoo loam (*YL*) | 0.4 | 0.2 | 1.3 | 3.0 | 72.4 | 22.5 |
| Wabash clay (*WC*) | 1.0 | 0.4 | 3.3 | 4.2 | 50.3 | 40.1 |
| Sharkey clay (*SC*) | 0.2 | 0.2 | 2.0 | 5.2 | 44.6 | 47.4 |

Since sand (silica) constitutes much of the load of streams and the sand grains are very durable and therefore relatively large, it follows that sand is quickly deposited and much of the sandy load is found in the soils of the front lands. These soils are, therefore, siliceous as compared with those of the back lands. Sands, sandy loams and loams are the prevalent types of front lands. The percentages of lime, potash and phosphoric acid in the front land soils are relatively low, although many of these soils have enough mineral plant food for crop use, and their excellent drainage on the whole makes them productive. On the other hand, the clays and silts of the back lands show high percentages of these plant foods in part because they are fine grained, a relation between texture and composition that has been before noted.

This typical variation in composition is illustrated in Fig. 126, and the accompanying table. The map shows the soils on a portion of the flood plain of the Kansas River. The belt of sandy soils here is relatively broader than on the flood plains of larger rivers, a comparison that usually holds for the flood plains of smaller rivers.

[1] Soil Survey of East Carroll Parish, La., U. S. Bureau of Soils.

The results are given in pounds per acre, assuming 2,000,000 pounds per acre, surface soil 7 inches deep.[1]

| | Phosphorus. | Potassium. | Calcium. |
|---|---|---|---|
| Osage very fine sand (*OS*) | 440 | 41,200 | 18,600 |
| Osage very fine sandy loam (*OF*) | 880 | 39,200 | 15,000 |
| Osage silty clay loam (*OL*) | 1,220 | 41,200 | 16,200 |

The surface drainage of front-land soils is fair or good because of the slopes and the underdrainage is helped by the porous textures. On the other hand, the drainage of the back lands, both surface and subsurface, is retarded by the level slopes and the relatively impervious fine-grained clays and silts that are characteristic. A feature growing out of the retarded drainage of the back lands is the high humus content of many of these soils. It has been noted, page 79, that vegetable matter often accumulates under such conditions of retarded drainage and such soils are likely to show a high nitrogen content. The humus and nitrogen account in part for the high fertility of these back-land soils when they are well drained.

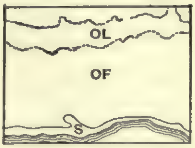

Fig. 126.—Soils on the Kansas River, Kansas.

**Variability of Alluvial Soils.**—While all alluvial soils are characteristically variable, yet, as a rule, the soils along large rivers, especially in the lower reaches, are less variable than those along the upper reaches and, other things being equal, the soils along small streams are more variable than those along large streams. Along the lower portions of large streams the currents are less variable because the slopes are gentle and, therefore, there is less variation in load that is deposited. Furthermore, the river's load is well mixed by its long journey and there is less local variation of materials. Thus, along the lower Mississippi one can be fairly certain that the river will be bordered by loamy front lands with wide belts of silts and clays on the back lands. The soils along the upper reaches of a river are often variable or "patchy." The slopes here are steeper than in the lower reaches so that there is greater variation in velocities between high and low water and, in consequence, there is a variety of materials deposited. Furthermore the load, as a rule, has had a shorter journey and is less thoroughly mixed.

Fig. 127 shows the variable soils in the upper part of the Sacramento River in California. The river descends from the mountains with a high velocity and con-

[1] Bulletin 200, Kansas Experiment Station.

sequently carries a heavy load, including gravel. When the river reaches the lower more flat country, the heavy gravels are dropped making large areas of gravelly soils. The variable velocities here explain the range of soils from gravels to silts, a complex arrangement in marked contrast to the simpler arrangement in the lower parts of the same river.

Alluvial soils are especially notable for sudden variations between soil and subsoil. That alluvial deposits vary vertically, as well as laterally, has been noted before, Fig. 120. A strong current may deposit coarse materials during high water and weaker currents of falling water may deposit finer materials. Again, slow currents may cover coarse deposits of former times with fine materials. In general, stream deposits tend to become finer from the bottom up, and sand and gravel are likely to be found in the lower sections of alluvial deposits and sands, silts and clays in the upper sections, although there are many exceptions to the rule. Very often a field, say of loam, will be well drained in some places and poorly drained in others and the soil auger will show differences in subsoils as the cause. As in soils, variations in subsoils are more common along small streams than large ones and in the upper rather than in the lower courses of rivers.

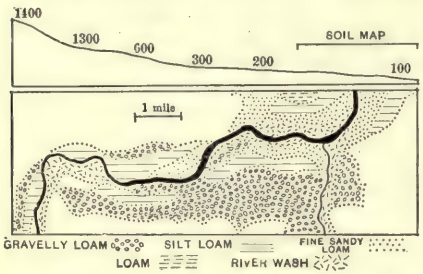


Fig. 127.—Soils of the rapid Sacramento River, Cal. In the profile above, the area below the words "soil map" is shown on the map below. The river flows from left to right. (U. S. Bureau of Soils).

## Flood Plains and Valleys

Flood plains occur most typically in the lower, rather than in the upper parts of valleys, for here the valley is usually wider and more likely to be flat so as readily to be overflowed and built up. If, as is the case in some places, the rocks in the lower part of a valley are more especially resistant, the valley may actually be narrower in its lower part as, for example, the Connecticut River, the lower valley of which is narrow and gorge-like and the upper valley is wider and the river is fringed by alluvial lands.

As erosion proceeds the river valley is widened up stream and the areas of flood plains also extend up stream. A feature of flood plains is that they are ordinarily bounded on either side by relatively steep slopes. These slopes may be so steep as to form bluffs if the valley has been widened by lateral cutting of the stream as shown in Fig. 128 or if the rocks along the stream are somewhat resistant. On the other hand, when the rocks in a stream valley are weak and are easily eroded. the valley sides may have slopes so gentle that it is difficult to determine where the flood plain ends and the valley sides begin.

Fig. 128.—A river meandering in its flood plain. The meanders are widening the valley, Canada. (Canadian Geological Survey.)

**Flood Plain Meanders.**—A river flowing through a flood plain seldom holds a straight course and if its course is straight it will soon become curved. The primary reasons for such common meandering habits are (1) that such streams usually have rather low velocity and are easily turned aside and, (2) furthermore, the incoherent materials of flood plains offer little resistance to changes in the stream courses. (3) The banks here of sand, there of clay, may offer unequal resistance to the currents and thus promote changes in the stream's course. Sunken boats or lodged timber have been known to start meanders, but very often a river will cut more on one bank than on the other for no apparent reason. A stream in a meander usually undercuts its bank beneath the surface of the water so that often acres of land will suddenly slump into the water along a long, narrow zone. Such undercutting is sometimes prevented by revetments, Fig. 129, which deflect the current from the bank. Flood plain meanders practically always characterize a river flowing through a flood plain. They differ from incised meanders, page 139, in that the valley follows incised meanders while flood plain meanders are quite independent of their valley.

Fig. 129.—Revetment in the Missouri River to prevent undercutting. The river is flowing from left to right.

**Development of Meanders.**—The work of a stream in a flood plain meander is much as is an incised meander except, of course, the changes are much more rapid in the former. The rapid current, Fig. 130, impinging against the banks at *A* and *B* erodes at these places more than elsewhere so that the meander not only moves laterally but down stream as well. Successive positions of the meander, due to these combined lateral and down-stream movements, are shown in the diagram. Often the meanders approach so closely to each other that, during high water, the stream breaks through the narrowed neck leaving the former meander as a curved "ox-bow" lake. When this happens the river shortens its course and the current is swifter, so that a new meander is likely to be formed because of the shifting of currents.

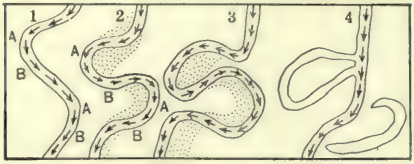


Fig. 130.—Diagram to illustrate the outward and down-stream movements of meanders (1 to 4). Arrows show the position of the rapid current. Dotted areas are those passed over by the river. At the right the meanders have been converted into ox-bow lakes.

When a meander is thus cut off from the main stream, it is filled at the ends, changes into a lake, the lake later reaches the swamp stage and in time the swamp becomes filled and can often be traced by the peculiar crescent-shaped areas of soils, Fig. 131. Fig. 132 shows an interesting example of vanishing ox-bow lakes. The upper lake is evidently the younger and the former meander can be traced for much of its course. The lower lake is but a remnant of a former ox-bow lake. The lakes are being filled with fine materials, mostly clays.

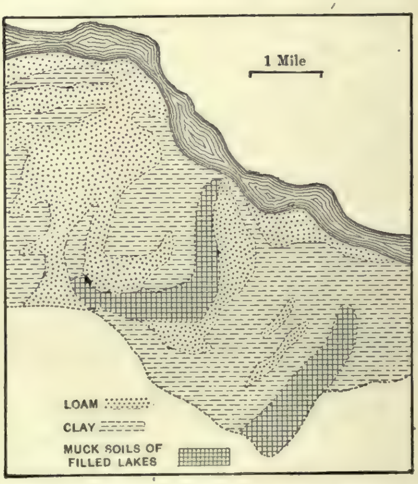


Fig. 131.—Former ox-bow lakes shown by muck soils, Missouri. (U. S. Bureau of Soils.)

**Deposition by Meanders.**—Not only does a meander erode as it moves outward and down valley but it deposits as well. The rapid current is on the outside of the meander and, in consequence, most of the cutting is done here. On the other hand, the water on the inside of a meander is more quiet and consequently deposition usually occurs here. This deposition on the inner portions of a meander is well shown in Fig. 133, which shows the meander building on the inner side (left) and cutting on the outer side (right). It will be seen that, as a meander moves down valley, it both removes and deposits materials and, when it is remembered that there are many meanders often following each other in the same stream, it will be evident that a vast amount of material is moved in this way. Moreover a long stretch of a river with its many meanders will swing from one side of its valley to the other, thus widening the valley. The lower Mississippi, for example, has undoubtedly widened its valley in this manner.

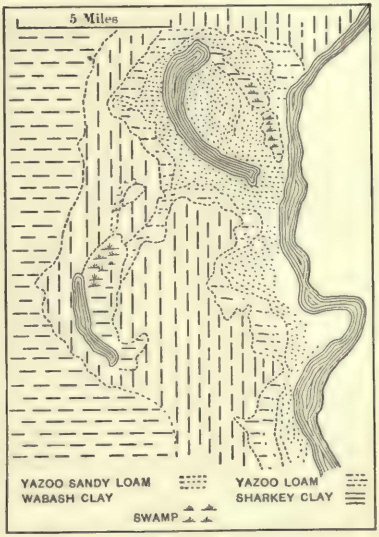

Fig. 132.—Partly filled ox-bow lakes, La. (U. S. Bureau of Soils.)


Fig. 133.—The Missouri River depositimg sediment on the inside of a meander at the left.

An example of the relation of soils to meanders along the lower Mississippi is shown in Fig. 134. The river formerly followed a course approximately along the line of arrows. The meander has moved laterally and down streamward leaving in its wake several square miles of newly made soils.

**The Settlement of Flood Plains.**—Flood plains are usually first occupied in the settlement of a region both because of their productiveness and because of their accessibility. The natural levee is higher and usually better drained than the back lands and this difference often leads to crop differentiation on front and back lands and, indeed these two divisions are often so clearly marked by crops that the crops map the soil types, Fig. 135. Very often the front lands are cleared while the back lands are in forest and here again the vegetation often marks the soils, the line of timber being near the boundary between the front and back lands. Because of this difference in soils, land lines on flood plains are often roughly perpendicular to the river so that the farm or plantation will include both soil types.

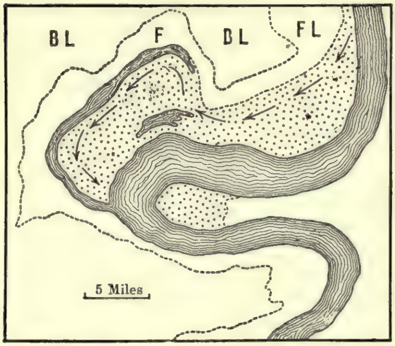


Fig. 134.—Showing the deposition of soils (dotted areas) as a meander of the Mississippi moves down stream. The arrows indicate approximately the former position of the river, Louisiana. (*FL*) front land; (*BL*) back land.

**The Mississippi Flood Plain.**—By far the largest flood plain in North America and one of the largest in the world is that of the Mississippi River. The main part of this flood plain extends from Cairo at the junction of the Ohio to the Gulf of Mexico. This area varies from 30 to 60 miles in width and has a length of about 600 miles, Fig. 136. Through this alluvial plain the great river meanders for a distance of about 1100 miles or about half that distance by air line. On either side for much of the distance are bounding bluffs of varying heights. The vast alluvial plain is really a complex of the flood plain of the Mississippi and its tributaries which usually flow roughly parallel with the main river before entering it. The back lands especially contain a network of small streams each fringed with its own natural levee. Many low ridges which were built as natural levees mark the courses of streams that have disappeared, Fig. 137. The population and cultivated lands

Fig. 135.—The front lands (loams) are in alfalfa; the back lands (clay loams) are in wheat, Kansas.

are mainly located in a relatively narrow belt along the front lands. The back lands of the Mississippi River are largely in timber and yield large amounts of lumber. Their drainage and utilization is one of the large problems in the farm development of the United States.

FIG. 136.—The alluvial plain and delta of the Mississippi.

### Alluvial Terraces

Many stream valleys are fringed by strips of level land which lie above the stream and flood plain and are called *terraces,* Fig. 138. The more or less level terrace surface descends toward the stream by a slope termed the *terrace face,* which is often relatively abrupt, but may occasionally be gentle. Not infrequently there are several terraces rising one above the other like a huge, rude stairway on one or both of the valley sides. Terraces are usually narrow, seldom being more than a few miles in width at most. They are seldom continuous for long distances and they lie at various heights above the stream, the lowest terrace sometimes being inundated by high water while some terraces are hundreds of feet above the valley bottom. Terraces are frequently termed "second bottom," "third bottom," etc., to distinguish them from the flood plain or "first bottom."

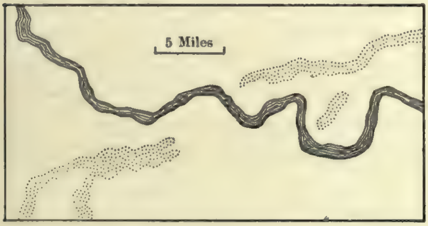

FIG. 137.—Low, loamy ridges (dotted) built by former streams on a flood plain, La. (U. S. Bureau of Soils.)

**Origin.**—Terrace materials are usually stratified and show all the indications of water deposition. They are remnants of flood plains most of which have been eroded and they, therefore, represent two phases of stream work. First, the stream must erode its valley and, then, owing to some change in conditions the stream must fill its valley to a considerable depth with alluvial materials. Subsequently, changing its habits from aggrading to degrading, the stream cuts down through the alluvial materials, leaving more or less of the old flood plain standing as alluvial terraces. The successive processes are illustrated in Fig. 139.

Some of the factors which cause changes in stream habits whereby terraces are formed are as follows: (1) A tilting and uplift of the land may make the grade of a stream higher, thereby giving it greater velocity and consequently sufficient energy to cut instead of deposit. (2) If there is an increase in volume without a corresponding increase of

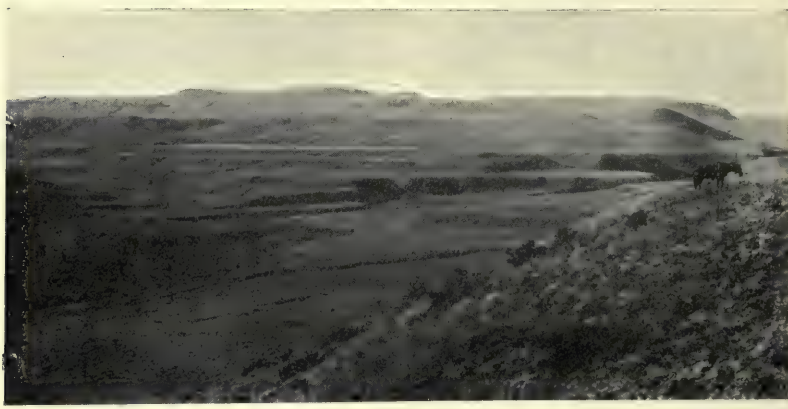

Fig. 138.—Alluvial Terraces, Washington. Note the level tops and steep fronts of some of the terraces. (Russell, U. S. Geological Survey.)

load, the stream may change from aggrading to degrading activities; such a result might result through a change from dry to moist climate. (3) If from any cause, a stream's load is decreased while other factors remain practically constant, the stream's energy expended in carrying the load is released and may be applied to cutting its bed. The formation of terraces was especially active at the close of the Glacial Period, when conditions were particularly favorable for terraces. During this period vast glaciers covered much of North America and Europe, Figs. 170 and 171, and, when the ice melted, the heavily laden streams flowing from the glaciers filled their valleys to depths of scores and hundreds of feet. Later the load was reduced and perhaps the land was tilted as the weight of the ice was removed and, as a result, terraces of glacial materials extend along many streams far beyond the limits of glaciation. This period is sometimes called the "terrace epoch" because of its many associated terraces.

It has been noted that terraces often rise one above the other like rude stairs. This means, in general, that there were as many successive cuttings as there are terraces. Such a series of terraces could be produced by successive uplifts of the land. For example, one uplift would cause the stream to erode its channel and leave the former flood plain remnants standing as terraces. If the land remained quiet for a sufficient time the stream might meander and destroy much of the terraces. A second uplift would result in another erosion of the second flood plain again leaving fragments of this flood plain as terraces. Thus each elevation might result in a terrace. Again there might be a variation in volume whereby a period of stream building might be followed by a period of stream cutting. Under such conditions we might find as many terraces as there were variations in volume. Finally, it may be noted that terraces might be made by the swinging from side to side of a series of meanders.

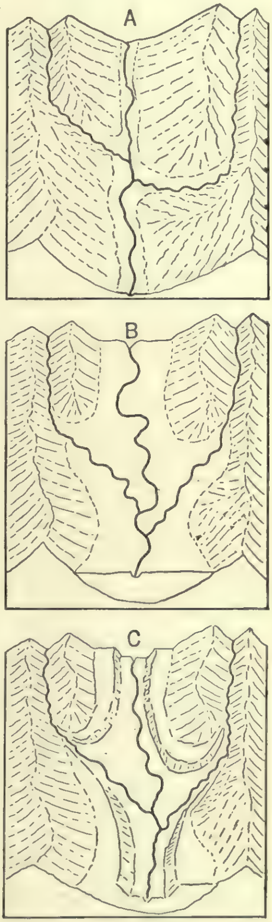


Fig. 139.—Diagram to illustrate (*A*) valley cutting; (*B*) valley filling; (*C*) terrace making.

In résumé it may be said that terraces are fewer due to destruction than action. For this reason terraces are discontinuous, for they have been completely destroyed in places; they seldom continue for more than a few miles at most.

**Terrace Soils.**—In general, the soils of terraces are likely to be coarser than those of the adjacent flood plains. This is especially true of glacial terraces, which have been mentioned before, since the streams which deposited these terraces usually carried coarser materials than the present streams. Terrace soils are commonly better drained than those of flood plains, both because of the higher elevation of terrace soils, and their usually coarser texture. In general, they contain less humus than flood-plain soils. A common textural characteristic of terrace soils is that they become coarser downward. That is, the subsoil and the materials below the subsoil are frequently gravelly while the soil may be sandy or loamy. This is explained by the fact that, as the original flood plain from which the terrace was cut was built up, the gradient of the stream became less and it, therefore, carried and deposited finer materials.

Terraces are older than the adjacent flood plains and higher terraces are older than lower ones. Consequently, the soils of terraces are relatively somewhat weathered as a rule. Old terraces may be so eroded as to have lost all traces of their former level surface and are only recognizable by a thin belt of characteristic soils. Fig. 140 shows the level surface of a young terrace bordered by an older eroded terrace. Old terrace soils may be so thin that they are underlain by a residual subsoil. Terraces, the upper parts of which are in contact with uplands, show gradations in soils from terrace to upland soils and, where there is a marked slope between terrace and upland, there is often a belt of soils which have been washed down from the upland. If the terrace soils resemble the upland soils, as is the case in some parts of the Coastal Plain, there is obvious difficulty in distinguishing between the two soils and, again, terrace soils may be weathered so as to resemble the upland soils rather closely. A contrast sometimes to be observed between flood-plain soil and the older associated terrace soils is in the subsoils. It has been noted that, in general, subsoils in humid climates are somewhat heavier than the soils owing to the action of ground water in carrying downward the finer silts and clays. This action requires a considerable time and older terraces may show very distinct heavy subsoils while younger terraces and still younger flood plains may show but little difference between the soil and the upper subsoil.

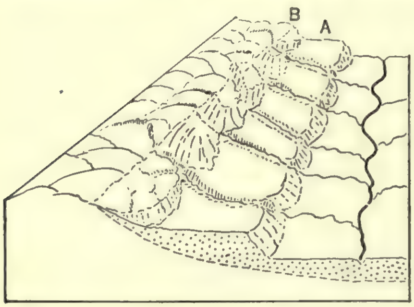

Fig. 140.—Diagram to illustrate (*A*) a lower, smoother young terrace and (*B*) an upper, older and eroded terrace.

## Alluvial Soils and Stream Basins

It is obvious that there must be a more or less close relationship between stream deposits and the ultimate source of the alluvial materials. For example, a stream draining a sandstone basin will usually deposit sandy materials, as do many of the streams flowing through sandy regions of the Coastal Plain. It must be remembered, however, that only a small number of important depositing streams drain basins that yield fairly homogeneous materials. Moreover, it is usually difficult to identify finer stream sediments as coming from a given locality, for it is one of the characteristics of stream transportation that the materials in transit are thoroughly mixed. Indeed, it is only when the stream load has a characteristic color or composition that its sediments are readily identified as, for example, the characteristic sediments of the Red River, hence its name. Again, the fertility of river soils is often as much a matter of texture as of composition, and texture is usually more dependent on stream sorting than on the original source of the sediments.

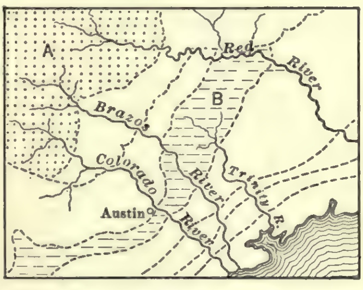

Fig. 141.—The Red, Brazos and Colorado rivers rise in regions of red Permian rocks ($A$). The Trinity River rises in a belt of chalks and marls ($B$) which furnish calcareous materials to this river.

**Examples.**—Fine examples of relations between stream basin and alluvial soils are found in Texas and adjoining states, Fig. 141. The Red, Brazos and Colorado Rivers rise in regions of Permian rocks which include much red sandstone and shale. Such materials color the alluvial soils of these rivers for more than three hundred miles down stream from the red rocks which yield the typically reddish soils (Miller series). On the other hand the neighboring Trinity River rises and flows for a considerable distance through calcareous materials which yield black, heavy alluvial soils. The Rio Grande farther south rises in the semi-arid regions of New Mexico and flows through regions of scant rainfall, and as a conseqence, its soils are but little leached, are light colored and are very high in lime.

Glacial deposits cover much of the upper Mississippi Basin, and their fine-grained materials yield the productive alluvial soils of that region. The high productivity of the lower Mississippi soils is doubtless due, in some measure, to the admixture of comparatively unweathered glacial materials which have been carried by the river for hundreds of miles. It is sufficient for our purposes to state that the glacial materials are mainly rock " ground up " by glaciers so that the materials are comparatively fresh and unweathered. We find somewhat characteristic alluvial soils in New England, where the rocks are mainly granite and gneiss. Another illustration is found in northwestern Washington, where alluvial soils from the glaciated region are underlain by fine sand while the alluvial soils from regions of residual soils have heavy subsoils. The explanation of the contrasting subsoils is to be found in the fact that, when the former extensive glaciers melted, the resulting large volumes of water carried and deposited the sands, which were later covered with finer silts as the depositing waters later lost their volume.

Streams often carry alluvial materials down stream into regions of different soils so that the soils of one region may, so to speak, be projected as long tongues into other regions. For example, the fine-grained soils from the Piedmont extend as narrow alluvial tracts through the sandy Coastal Plain, and the projection of glacial materials as alluvial soils far southward of the original locations has been noted on preceding pages.

## Deltas

Deltas are built where streams enter relatively quiet water where the stream velocity is suddenly checked and thus rapid deposition is brought about. Not all streams built deltas; the Niagara River, for example, has not built a delta into Lake Ontario, for the river carries little sediment as it flows from Lake Erie. Again, if there are strong tides, waves or currents at the mouth of a stream they will carry away the sediment that would otherwise be built into a delta. Deltas are, therefore, the " triumph of river deposition over wave and current destruction " (Grabeau). Because waves, tides and currents are stronger in oceans and seas than in lakes, deltas are usually more abundant in lakes, although the larger deltas are usually built into seas because here they are built by the larger rivers. The Mississippi delta, for example, while it is commonly said to be advancing at the rate of about 300 feet a year, is nevertheless suffering from considerable erosion, as shown in Fig. 142.

If a coast is rather smooth, the delta often projects beyond the coast line, but when a stream empties into a bay, as the Susquehanna into Chesapeake Bay, the delta simply fills the bay and the delta outline is more or less governed by the shape of the bay, as shown in Fig. 143, where the Payallup River is building its delta into Commencement

Bay, an extension of Puget Sound. Here, as usual, the coarse materials are deposited near the mouth of the stream, the finer materials are carried into more quiet water and there deposited. The marsh near the lower part of the delta will be built up into arable land and the water near the delta will become shallow and then give way to marsh.


Fig. 142.—Map of the "passes" of the lower Mississippi delta showing the areas gained by deposition and those lost by wave and current erosion. The black areas show the area of the delta in 1872, the lined areas, the regions of deposition and the dotted areas, the regions eroded. (U. S. Coast and Geodetic Survey.)

**Growth of Deltas.**—In considering the formation of deltas, a simple, somewhat ideal, case will be taken. Suppose the stream, Fig. 144*A*, carries a heavy load of sediment. When the stream reaches quiet water, the bulk of its load, especially the coarser load, will be dropped near the stream mouth while the finer materials will be carried farther out. The mass of debris first deposited tends to reduce the grade of the stream and makes the single channel unable to carry the water and sediment so the stream escapes through *distributaries*, Fig. 144*B*. These distributaries become aggrading streams and build up natural levees and back lands much the same as streams in a flood plain and, moreover, the distributaries themselves develop smaller distributaries. Between the growing distributaries are *delta lakes*, Fig.

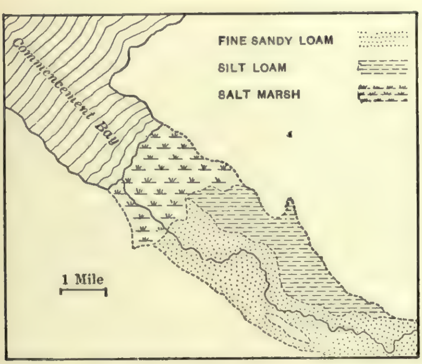


Fig. 143.—Soils of the Puyallup River delta, Oregon. The river is building its delta into Commencement Bay. (U. S. Bureau of Soils.)

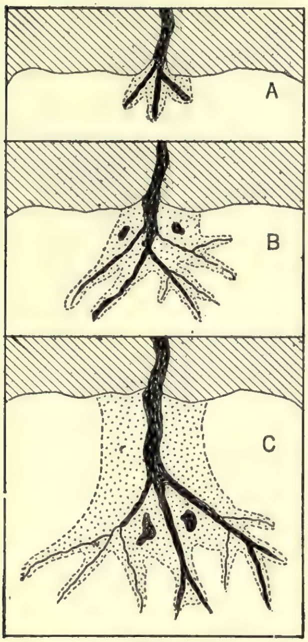


FIG. 144.—Diagram to illustrate possible stages in delta building.

144 *B* and *C*, which become filled with sediment brought by overflows and the areas of which become lessened by the widening of the natural levees. In time the lakes are mostly filled and the older parts of the delta are built above sea level as a fairly continuous land area, while the processes outlined above are continued farther seaward. Thus the delta in its older portions is built into a low, level plain, interrupted here and there by deserted natural levees, sluggish streams and shallow delta lakes, while beyond to seaward the partly completed delta is in process of building.

It should be kept in mind that the simple, ideal conditions stated above seldom apply in all respects to any delta because of the many complicating factors, such as the rising or sinking of the coast, waves, tides, currents, variations in the river load and velocity, and perhaps other factors. The idea to be emphasized in the usual growth of deltas is their ultimate conversion into *delta plains*, which are practically extensions of the flood plains above, and no definite line of division between the delta plain and the flood plain above can be drawn. The great Mississippi Delta is a case in point, Fig. 145. Locally the part projecting below New Orleans is called the delta, while some geologists would place the head of the delta some 250 miles up the river where the first distributaries are given off. Some of the world's large deltas are built by two or more rivers. Holland


FIG. 145.—Map of the Mississippi delta showing the distributaries from the Red River southward.

is a classical example of delta reclamation; it is located in part on the combined deltas of the Rhine, Meuse, Sambre and Scheldt. The combined deltas of the Ganges and Brahmaputra in India are estimated to cover between 50,000 and 60,000 square miles. The intricate network of depositing distributaries of these rivers is shown in Fig. 146.

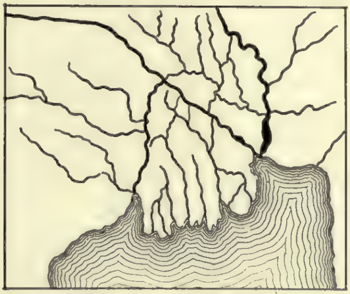

FIG. 146.—Combined delta of the Brahmaputra and Gànges rivers. (After Geikie.)

**Classes of Deltas.**—There are two classes of deltas that possess such different geological and agricultural features that they deserve separate descriptions. First are the deltas of slow streams with low gradients like the Mississippi River; these deltas have been considered in the foregoing paragraphs. Second are deltas of rapid, high-grade streams. Deltas of rapid streams are necessarily built of relatively coarse materials because the constructing streams can carry gravel as well as sand and silt. The heavy load falling near the stream's mouth is built into a level-topped delta with a steep front, steep because the coarser materials will lie at rest at a higher angle than finer materials. The silt, fine sand and clay are spread out beyond the delta front. Such deltas are especially characteristic of lakes and bays surrounded by somewhat high land with streams flowing down considerable slopes. Many such lakes of large extent formerly existed in the Great Basin and most of these lakes have been wholly or partially drained and their dry deltas now stand forth on the valley sides much as when they were built. The former Lake Bonneville, Fig. 233, has many such deltas of considerable area. Typically, such deltas have sandy or gravelly soils in their upper portions and silty soils on the lower slopes leading away from the deltas into the old lake bottoms.

FIG. 147.—Seward, Alaska. The town is located on a delta built by a rapid stream. (U. S. Geological Survey.)

These delta soils are of especial economic importance around the eastern margins of the Great Basin, for irrigation water can often be obtained here.

The old delta of the American Fork River in Utah is an excellent example. When the Great Basin was in part occupied by Lake Bonneville the river, a rapid stream heavily loaded with debris, built a large delta or rather a series of deltas at different levels of the lake. This delta, including several thousand acres, projects into the valley as a prominent topographic feature and the American Fork River and Dry Creek have now cut their channels in places to the base of the delta; otherwise, the prominent deltas remain much as they were when the lake waters were drained away. The soils shown in Fig. 148 have the common arrangement of gravelly soils in the main body of the delta with finer-textured soils about the delta margin. The delta top heading at the stream canyons is easily irrigated. The small areas of clays are believed to have been washed down into depressions since the lake waters withdrew.

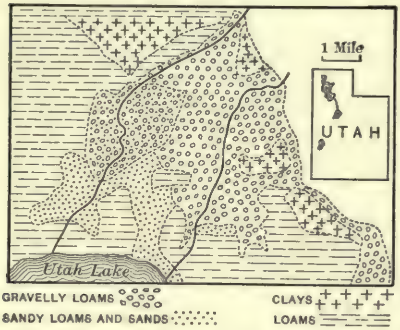


FIG. 148.—The soils of the old delta of the American Fork River, Utah. (U. S. Bureau of Soils.)

Much of the same kind of deltas are found where there were formerly lakes due to glacial action; these deltas will be considered in a later chapter. Such a delta is shown in Fig. 229. These exposed "dry deltas," while of comparatively small areas, are of greater agricultural interest than many larger deltas of the present, since the latter are mostly submerged and only a small part of their areas are available for cultivation.

**Delta Materials.**—All large deltas are built by large rivers, although not all large rivers build deltas. Large rivers and all rivers with low gradients have relatively slow currents in the lower courses where the deltas are built. Their deltas are, therefore, mainly composed of fine materials such as clay, silt and very fine sand and their available soils are, therefore, heavy. Such deltas are important both because of their extent and the general fertility of their soils. In contrast with the deltas of extinct lakes, only the tops of present deltas are exposed to yield soils since the rest of the delta is submerged. The fineness of Mississippi Delta materials is indicated by the following table, which shows the mechanical analysis of a composite sample selected from 235 samples of the delta materials:

| Fine gravel (2 to 1 mm.). | Coarse sand (1 to 0.5 mm.). | Medium sand (0.5 to 0.25 mm.). | Fine sand (0.25 to 0.1 mm.). | Very fine sand (0.1 to 0.05 mm.). | Silt (0.05 to 0.005 mm.). | Clay (0.005 mm. or less). |
|---|---|---|---|---|---|---|
| .3% | .5% | .2% | 6.5% | 28.2% | 51.2% | 13.0% |

[1] E. W. Shaw, Professional Paper, No. 85, U. S. Geological Survey, 1914.

**Delta soils** show essentially the same distribution as those of flood plains since, as the delta is built, its upper portions constitute an extension of the flood plain which becomes longer as the delta is extended. Delta surfaces are level except where they are interrupted by low natural levees or delta lakes. The soils are rather uniform, although the variation from coarse to fine textures is seen along the distributaries as along flood plains. Marginal portions of deltas are commonly too low and marshy for cultivation except by reclamation methods. A somewhat typical soil distribution is seen in the Rio Grande Delta, which is mainly constructed of fine materials, Fig. 149. Along the distributaries, present and past, are found the silty clay loams which were deposited by relatively rapid currents during overflows, a relatively light soil here, although the sand content is very low. Clays were deposited between the distributaries of the delta and along its margin where the river currents were checked by the Gulf. The clay areas contain some unfilled depressions now occupied by lakes. The silt loams are found in the upper and newer areas of the delta and along the flood plain although here, as elsewhere, there is no sharp distinction between delta and flood plain.

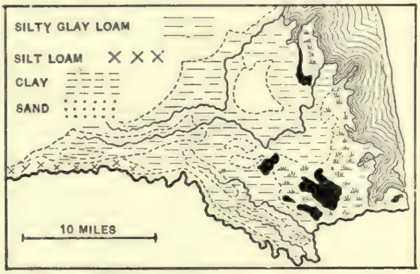

FIG. 149.—Soils of a part of the Rio Grande delta. (U. S. Bureau of Soils.)

## Alluvial Fans and Cones

Alluvial fans and cones are delta-like deposits built on the land. Small fans and cones are commonly to be seen on pavements and in ditches when a little rill descends to a level slope and there, losing its carrying power, drops much of its load in a fan-like or cone-like shape. Fans and cones are in many respects much like deltas built

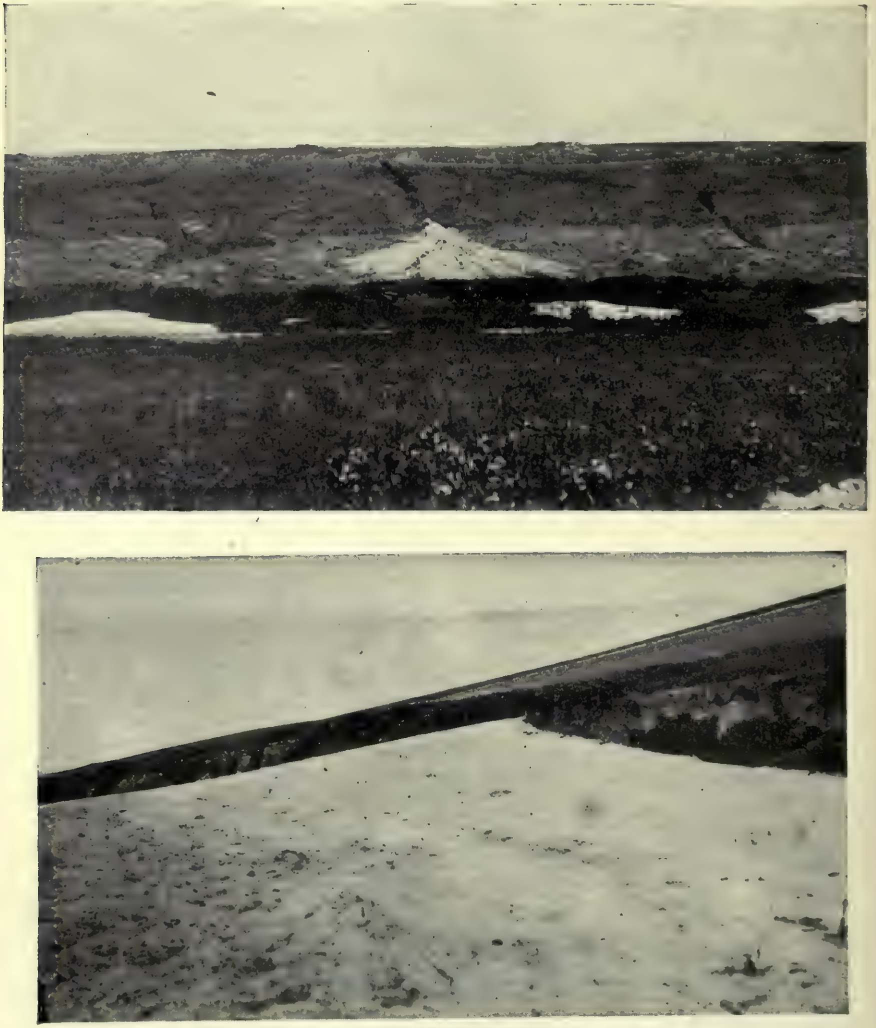

FIG. 150.—Above, a small alluvial fan, front view. Below, profile view of a small alluvial fan, California. (Professor C. F. Shaw, University of California.)

by high-grade streams and, in fact, some fans are built into water and form deltas.

**Origin.**—Fans and cones typically occur at abrupt changes in stream slopes as where mountains abruptly descend to plains. The mountain streams lose their velocity and drop their coarser materials near the mouths of their gorges and these coarse materials often clog the stream so that it divides into several distributaries much as those of deltas. The coarser materials ordinarily make steeper slopes near the apex, while finer materials are carried farther down the fan and built into more gentle slopes. The distributary channels, often termed "washes," are usually dry much of the year. When the slopes are steep the form is termed a cone and when more gentle, a fan, although both forms merge into each other; fans are by far the more important forms. Fans and cones ordinarily have roughly semicircular outlines with lobed margins and lobes of which as, in some deltas, extend outwards where distributaries have built them.

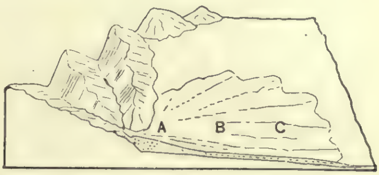

FIG. 151.—Diagram to illustrate the building of an alluvial fan.

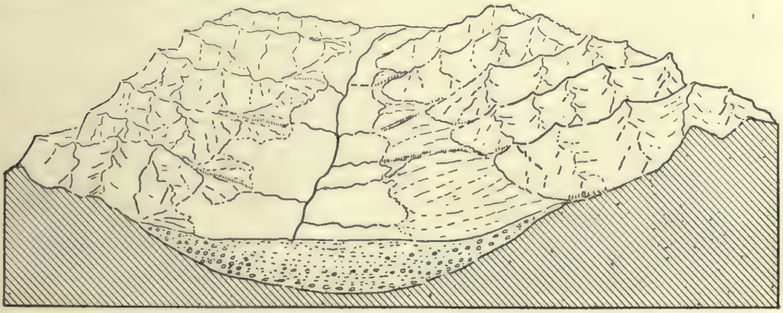

FIG. 152.—Diagram to show simple and coalesced alluvial fans. The mountains on the right are higher and the streams have built the larger alluvial fans which have grown together to form a piedmont plain.

In Fig. 151 the high-grade stream reaches lower grades at *A* where it quickly deposits its heavy load such as boulders, stones and gravel; the sand is carried farther out into zone *B* while fine sand, silt and clay are borne still further from the apex in decreasing quantities so that the margin is usually indistinct. Often the feeding stream disappears in the apex and reappears in the lower portions. Fans and cones are largely built by streams in flood. Very frequently they enlarge until they unite at their margins, thus forming a compound alluvial fan or *piedmont plain*, Fig. 152.

**Favorable Conditions.**—Conditions favorable to the formation of fans and cones are of two sorts, topographic and climatic. The importance of an abrupt change of slope, such as ordinarily occurs where level plains are bordered by hills or mountains, has been noted. Especially important areas of fans in North America are at the western base of the Sierra Nevada Mountains in California and at the eastern base of the Rocky Mountains. Huge fans have been built at the base of the Himalaya Mountains in India and at the base of the Andes in Argentina. Small fans are very common in all mountains and houses are often built on them. The most favorable climatic conditions for alluvial fan building are found in dry regions. Dry air promotes rapid evaporation and this process is especially effective when the fan-building stream divides into distributaries. Evaporation and the absorption of the water by the underlying porous materials of the fans reduce the volume of the distributaries, thus aiding deposition. Furthermore, the rains in this region are often torrential and feed rushing streams of high-carrying power which carry to the fans heavy loads of coarse materials. Finally, fans and cones built in a dry climate are much less liable to destruction by erosion and are preserved while, on the other hand, these forms in humid climates are likely to be destroyed or at least poorly preserved.

**Notable Regions.**—In North America the combination of high-sloped streams with abrupt changes of slope and dry climate is found in the valley of California, Fig. 153. The torrential rainfall in the Sierra Nevada Mountains is carried by swift mountain streams which deposit their load in united alluvial fans along the base of the mountains as a very gently sloping piedmont plain. Here, as in many other places, the upper portions of the fans grade into the coarse materials (talus) which creep and fall down the steep slopes. The mountains on the western side of this valley are lower and have less rainfall so that the fans from them are less extensive, a condition illustrated in Fig. 152. A favorable agricultural factor in the fans is the comparative ease with which irrigation water is led from the building streams over the slopes of the fans. In some regions mountains have been buried for hundreds of feet largely by the fans and cones which have been built around them.

The High Plains, extending from the Rocky Mountains eastward, are believed to be essentially vast coalesced alluvial fans of great extent.[1]

[1] The High Plains and their Utilization, Willard D. Johnson, 23d Annual Report, U. S. G. S., Part 4, 1899–1900.


Fig. 153.—Northern part of the valley of California. (U. S. Geological Survey.)

Much of this area is so level that water stands upon the surface, but nevertheless the High Plains as a whole rise very gently hundreds of feet until their western margin is nearly a mile above sea level. It is believed that this plain was built during a period of heavy rainfall by streams which flowed eastward from the Rocky Mountain region. Much of the material is well rounded, thus indicating a long journey by water and the pebbles are composed largely of crystalline rocks found to the westward in the mountains. In structure the High Plains are composed of irregular beds of gravel, sand and silt, much as are found in recent alluvial fans.

**Soils.**—While the soils of alluvial fans like those of deltas are transported by water, yet there are many contrasts. The soils of fans and cones are relatively coarse, typically of sands and gravels, because first they have been transported but a comparatively short distance and secondly in the characteristic dry regions the rocks are broken down mainly by disintegration and this process typically yields coarse materials. Then naturally, it follows that in the dry regions these soils are comparatively unleached and ordinarily contain abundant mineral plant food, but, however, the amounts of plant food will obviously depend on the parent rocks. Since the streams building fans are comparatively short and their basins small, the materials in the soils show a close relationship to the original rocks, a much closer relationship than is usually found in delta soils.

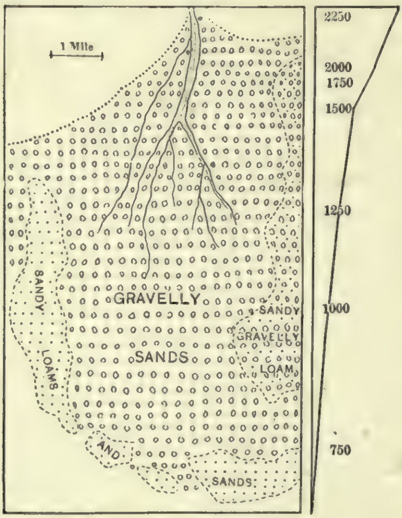


Fig. 154.—Soils on a portion of a piedmont alluvial fan at the base of the Sierra Nevada Mountains, Cal. The numbers with the profile on the right show the altitudes. (U. S. Bureau of Soils.)

In general, the soils of alluvial fans are gravelly or sandy, typically coarse gravelly sands in the upper and higher portions grading to sands and sandy loams in the lower portions. The distributaries or " washes " are commonly dry and marked by long tongues of coarse gravel. The distribution of soils is naturally somewhat irregular, owing to variations in the volume and load of the feeding streams. The map, Fig. 154, shows the soils on a portion of a compound alluvial fan in the Valley of California. In this case the coarse gravelly materials cover most of the fan while the sand and sandy loams are on the mar-

FIG. 155.—Alluvial fans extending from the base of the Coast Range, Cal. The fans are much eroded. (Prof. C. F. Shaw, Univ. of Cal.)

ginal portions. It must be remembered, however, that the relative proportions of coarse- and fine-textured soils vary greatly in different fans.

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## THE CYCLE OF EROSION

It is at once evident that the topography produced by erosion will change as erosion goes on. There is considerable aid in understanding and interpreting land surfaces if they are divided into three stages, *youthful, mature and old;* youthful, when most of the work of a stream system is yet to be done, mature when stream erosion is at its maximum, and old when erosion has nearly finished its work. The time required for a land surface to pass through these three stages is termed the *cycle of erosion.* It should be remembered that youth, maturity and age are *stages*, not ages. The oak, for example, is young at seven months, while corn is old at that age. Similarly, a region underlain by weak rocks may be worn to late maturity or age while an adjacent region underlain by strong rocks may still be in youth. For example, the upper Osage valley in Missouri, Fig. 156, is underlain mainly by weak shales and is worn to a rolling surface nearly in the stage of age while the lower valley which is really older in *age* is underlain by resistant sandstone, the surface of which is in rugged maturity.

The cycle of erosion can, perhaps, be best explained by a somewhat ideal case as follows, Fig. 157.

**Youth.**—Let us assume that a fresh uneroded surface underlain, say, by limestone is exposed to erosion. At first the streams are not numerous and there are but few tributaries. Streams flow in narrow, steep-sided valleys because there has not yet been time for deep, wide valleys to be developed. Divides are flat and often poorly drained with, perhaps, lakes and swamps. The run-off is low and much of the rainfall sinks into the ground or stands for a long time on the surface. An excellent example of youthful topography is seen in the valley of the Red River of the North. Formerly the site of a lake, the smooth lake bottom has been eroded but a short time as time is estimated in geology.

**Maturity.**—As erosion goes on the topography changes. Stream tributaries increase in number, valleys are worn wider and deeper and slopes become steeper. Divides become narrower and sharper. Rainfall finds its way quickly into the streams and erosion is at its maximum. Lakes and swamps have been filled or drained. Late in this stage the lower portions of streams have become graded, they swing from side to


Fig. 156.—The upper Osage valley is underlain by weak rocks (*W*) and is eroded to an old surface. The lower valley underlain by strong rocks (*S*) is eroded only to a mature stage. The river flows from left to right.

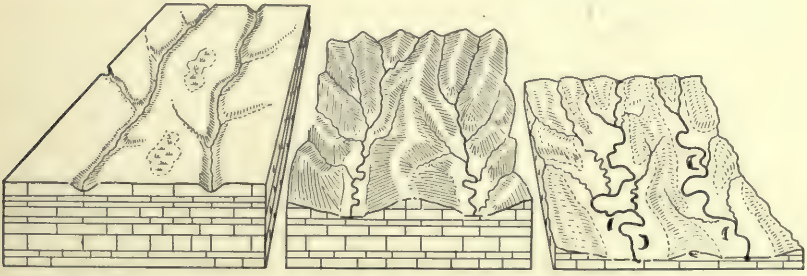

Fig. 157.—Diagram illustrating the cycle of erosion. The area in youth at the left changes to maturity and later to age.

side, thus widening their valleys, and narrow strips of flood plain may be laid down. Such an area is often described as mountainous. Many areas of the Allegheny and Cumberland Plateaus are in this stage.

**Age.**—With the passing of maturity, the larger streams begin to lose their vigor and deposit rather than cut, except as they may swing from side to side and cut laterally. The valleys become shallower, both from filling and from the wearing down of the divides, which assume low, rounded contours. Stream erosion, so effective in the preceding stages, is largely replaced by weathering and solution. The sluggish streams meander in wide valleys. In short, the agents of erosion are working slowly and the land surface is very slowly reduced. Where this stage is prolonged, so that the land is worn to a low featureless plain but little above sea level, such a plain is called a *peneplain.*

There are considerable areas in eastern Kansas and western Missouri which have been eroded to an old stage because the underlying rocks are easily eroded, Fig. 158. Indeed so long a period is required to reduce a surface to age that no large typical area in this stage has been found. In past ages, however, peneplains have been formed and re-elevated and their old level surfaces are preserved on hill and ridge tops. Such a peneplain is indicated in Fig. 58, where the old level surface is preserved on the ridge tops.

Fig. 158.—The rocks (shales) are weak and have been worn to a stage of early age, Southwestern Missouri.

**Stages and Soils.**—Agricultural conditions and soils show close relations to the stages in the cycle of erosion. In youth the run-off is slight, much water soaks into the ground and leaching is at a maximum. Typically the drainage is poor. The surface is level and well adapted to the use of labor-saving machinery. In maturity, slopes are steep, soil washing and erosion are at the maximum and soils are thin and stony. Arable land is at the minimum and the regions are typically adapted to grazing and forestry. As the stage of age is reached, the slopes again become gentle, the topography loses the ruggedness of maturity and becomes rolling. As in youth solution and leaching become prominent and a deep mantle of residual soil covers the uplands, a mantle which has been thoroughly weathered. Alluvial soils are of considerable extent and the percentage of arable soils is high. While there are no large areas that are in typical age, there are many small areas that are worn down to gently rolling surfaces.

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## CHAPTER IX

## SOIL CREEP. COLLUVIAL SOILS

**Introductory.**—It is evident, even to the casual observer, that fine soil and rock particles are being washed from the lands into streams and carried into oceans by the agency of running water. The much slower movement, by which the waste from the lands is as surely moving to the oceans, is usually overlooked. Occasionally a boulder on a steep slope can be observed to have moved down slope a few inches during a generation; of course, the mantle rock adjacent to the boulder has also moved, but its progress is not so readily noted. Again, to use another illustration, the boulder and its adjacent mantle rock may slide down slope as an avalanche. These two movements, the one very slow and the other rapid, are mainly due to gravity without the aid of running water. Except where the surface is level, there is this slow movement of mantle rock the world over. Both the slow creep and the relatively rapid landslides are sources of trouble in railroad construction and maintenance, since the movements displace the tracks. The landslides along the Panama Canal have become famous. There is no widely accepted term to apply to this movement as a whole, by which land waste is moved down slope without the aid of streams; it may be considered under three heads: (1) *soil creep or solifluction,* (2) *talus accumulations* and (3) *landslides.* Soils due to these processes are termed *colluvial soils.*

**Soil creep,** as the name implies, is the very slow movement of land waste down slopes, " a slow washing or creeping of the waste down the land slopes; not bodily or hastily but grain by grain, inch by inch; yet so patiently that, in the course of ages, even mountains may be laid low " (Davis). It is usually imperceptible from generation to generation, although leaning trees often indicate this movement.

**Factors.**—(1) The primary agent of soil creep is gravity and the primary factor is slope. Other things being equal, soil creep, like the analogous flow of streams, is the faster the steeper the slope. (2) If the soil mantle is saturated with water, friction between the particles is lessened and the creep is accelerated; there is no sharp distinction between water filled with land waste and land waste saturated with water, each moving down slope. (3) When water freezes and expands in the pore spaces of soils and other mantle rock, the particles are slightly lifted and, as thawing follows, the particles sink back vertically on level areas but diagonally on slopes. This is illustrated in Fig. 159, where it is seen that the successive frost heavings result in a very slow migration of particles down slope. Thus the whole mass of loose rock, gravel, sand, clay and soil moves down hills and other slopes, pausing here and there behind obstructions or where the slopes become more gentle, Fig. 160. (4) Finally, the loose materials come to rest at the foot of a slope and begin to accumulate, provided they are not washed away. As the detritus accumulates the slopes become more gentle and so facilitate further deposition until a low bulging or " shoul-

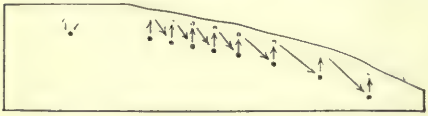

Fig. 159.—Diagram to illustrate the movements of soil particles due to freezing and thawing on level and on steep slopes.

Fig. 160.—Whiteside Mountain, Southern Appalachians. Soil lodging and accumulating on more gentle slopes. (Glenn, U. S. Geological Survey.)

der " of colluvial materials may be built, Fig. 161. Some kinds of artificial terraces are completed in part by soil creep; when a retaining wall is built in some regions of rapid soil creep, the space on the uphill side of the wall will be filled to some extent with colluvial soil.

FIG. 161.—A "shoulder" of colluvial soil at the base of a sandstone hill. The buildings are on the colluvial soil, Kansas.

**Associated Agents.**—Like most other geological processes, soil creep seldom acts alone, but cooperates with other agents. For instance, it is nearly always accompanied by *sheet wash*, that is, the flow of water over the surface as a sheet instead of as a stream. This can easily be observed on a small area during a heavy rain; the areas affected are small, but there are many of them, and they are largely confined to the uppermost portions of the mantle rock, Fig. 162. Closely allied with the sheet wash is the slower movement down slope of the upper ground water which carries fine silts and clays for short distances.

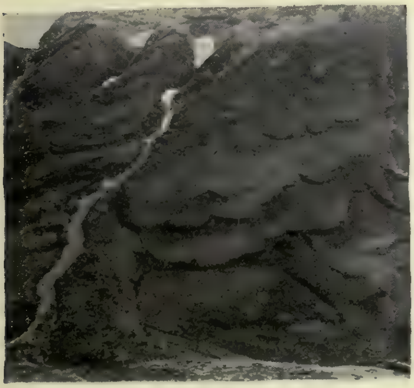

FIG. 162.—Sheet wash, Alaska. (Moffit, U. S. Geological Survey.)

Important areas of soils affected by these movements are found around the heads of streams where head erosion (page 137) is active and the steeper slopes here favor active soil creep. Another important cooperation of agents producing soil creep is seen on long, gentle slopes. The slow journey of the rock fragments allows the processes of weathering to act on them for a long time and the rocks become progressively smaller as they move down slope. As a consequence there is often a fairly regular change from stony ground on upper slopes through stony loams, gravelly loams, sandy loams to fine-textured loams on lower slopes.

FIG. 163.—Contour terraces to hold colluvial soil and to prevent soil erosion, N. C. (U.S. Bureau of Soils.)

**Differential Movements.**—It should further be noted that not all loose materials move down slope at the same rate. Unless the slopes are so steep that they roll down, the rocks and boulders move much slower than the fine materials and, as a result of this differential movement, the rocks and boulders lag behind the sand, silt and clay so that the upper slopes are stony while the lower slopes are covered with fine-grained colluvial materials. A typical illustration is shown in Fig. 164 which shows soil sections of limestone hills, one flat topped and the other curved topped. The steep slopes are stony because much of the finer material has moved down to the belt where colluvial soils are accumulating. The level surface of the flat-topped hill favors the formation of a residual soil, but in time its summit, like the other, will be eroded to a curved surface when its soils will become stony. In résumé, it may be said that in regions of colluvial soils the upper zone is typically of coarse textured, often stony soils, where erosion and soil creep is predominant and the lower, narrower zone is composed of fine-textured soils where accu-

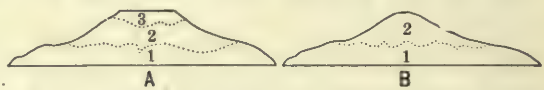


FIG. 164.—Diagram to illustrate the occurrence of residual and colluvial limestone soils on (*A*) a flat-topped hill and (*B*) a round-topped hill. (1) colluvial loams; (2) stony loams; (3) residual silt loams.

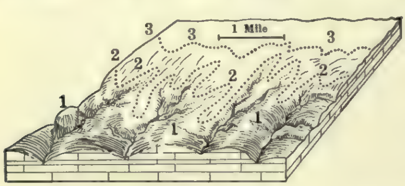


FIG. 165.—Diagram to illustrate the effects of soil creep and head erosion on limestone soils, Kansas: (1) stony loam; (2) shallow stony loam; (3) silt loam. (Data from U. S. Bureau of Soils.)

mulation is predominant. In other words, erosion, including soil creep, sheet wash and the head erosion of streams exceeds weathering on upper slopes while weathering and accumulation predominate on lower slopes. Some of these effects are shown in Fig. 165.

## Soil Creep and Rock Variation

Not all colluvial materials are so simple in origin. A complicating factor is the variety of rock from which the soils are derived, as is indicated in Fig. 166. In one case, Fig. 166*A*, a phosphatic limestone (*LS*) is underlain by shale. The fine sands and clays, together with soluble phosphates and bits of the limestone, will move down the slope, mingle with the silts and clays from the shale (*SH*) and accumulate over the less productive sandstone (*SS*), forming a belt of fertile colluvial soil. On the other hand, if the less productive sandstone is at the top of the slope, the sand and sandstone rocks, together with the materials from the shale, will cover the productive limestone soils with a much less fertile soil belt. These will illustrate two of the many rock variations which complicate the distribution of colluvial soils.

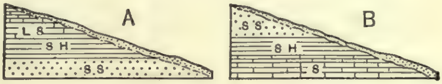


Fig. 166.—Diagram to illustrate origin of colluvial materials. (*LS*) phosphatic limestone; (*SH*) shale; (*SS*) sandstone.

In general, it may be said that in sandstone regions with colluvial soils, the upper slopes are sandy if the sandstone is weakly cemented and stony if the underlying sandstone is resistant; on the lower slopes the colluvial soils are composed of the very fine sand and silt that has moved down slope. In limestone regions the upper belt is very likely to be strewn with cherty fragments since most limestones contain some of this resistant material. The lower colluvial belt of limestone soils is often a silt loam containing fine chert grains. The soils from shales in hilly regions are variable but, in general, the upper slopes are often "slaty" or largely of shale loam and the colluvial soil belt is often silt or clay loam with which are intermingled flat fragments of shale. The colluvial soils from granites, gneisses and schists are extremely variable and about all that can be said in this connection is that there are usually the two typical upper and lower zones of relatively coarse and fine materials. In limestones and sandstones especially and in many other rocks as well, a soil map gives a fairly accurate topographic map so far as the slopes are concerned, the stony soils mapping the upper slopes and the colluvial the lower slopes.

Not only are soil creep and the commonly associated soil erosion found in regions of hard rock, but these processes are pronounced in many regions of unconsolidated rocks. Some of these formations are relatively young and soil creep has not been in operation long enough to produce well-marked colluvial soils and some of the young formations like the sandy Lafayette Formation in the South are so porous that the rains sink without much surface wash or creep. Even in these formations, however, the hill tops are very often more sandy than the

Fig. 167.—Both soils are derived from sandy shales. In the region on the left, the slopes are so steep that the soils are stony loams. The more gentle slopes on the right have caused the formation of silt loams, W. Va. (U. S. Bureau of Soils.)

lower hill slopes. Soil creep, together with some soil erosion, is seen in hilly regions of glacial materials where drumlins, which are hills composed mostly of clay, Fig. 191, often have slightly eroded tops, locally called "balds."

## Colluvial Soils

While theoretically the soils on all slopes are subject to soil creep, yet the term colluvial soils is restricted to belts of soils which have crept down slopes and accumulated in belts wide enough to have agricultural interest. They are most important in hilly and humid regions, although they are often found in arid regions as well. The aggregate areas of soils affected by soil creep is very large and includes nearly all habitable areas where there are well-marked slopes. In regions like the limestone Ozarks of Missouri the narrow belts of colluvial soils are in many places the only available soils and roads are run on the adjacent stony areas so as to save the colluvial soils for cultivation. Here, as in many other places, the upper stony areas are usually left in timber and brush, while the lower slopes are cleared, and many farms here include large stony areas for pasture and much smaller areas of colluvial soils for crops.

The famous "black pippin soil" in the coves of the Blue Ridge of Virginia is largely colluvial. These coves are made by head erosion as streams push their headwaters back into the crystalline rocks. The loose materials are washed into or creep into these coves faster than the small streams can remove them so that a deep, rich, black soil has accumulated. This soil, together with the protection from winds that is afforded by the cove walls, has made these coves very favorable locations for orchards.

### Talus

Talus is an accumulation of materials, mostly coarse, at the foot of steep slopes. These accumulations belong in the same class, so far as origin is concerned, as colluvial soils into which their materials often grade and with which their materials are often intermingled. The rate and kind of talus accumulations are influenced by three factors, (1) steepness of slopes, (2) resistance of the rocks, and (3) climate.

(1) *Steepness of slope.*—In regions of steep slopes the coarse materials move so rapidly that they are not much weathered in transit and they arrive at the slope base in large, angular fragments. When slopes are more gentle, the fragments undergo a slower journey, they are longer subject to weathering and the fragments are smaller. It has been noted before that long, gentle slopes favor finer colluvial materials more than short slopes. (2) *Resistance of rock* is an obvious factor. Other things being equal, the talus materials from quartzite ledges, for instance, will be coarser than those from limestone ledges. In this connection, it must be remembered that mountainous and hilly regions are usually underlain by resistant rocks so that talus materials are characteristically coarse. (3) *Rapidity of weathering.* The more active the weathering processes, the finer will be the colluvial materials when they arrive at the bases of slopes. A humid climate is less favorable for talus accumulations, for the materials are finer and there is more running water to wash them away. The most notable talus accumulations are, therefore, found in arid and semi-arid regions. In some parts of the Great Basin mountains are partly buried in their own talus materials.

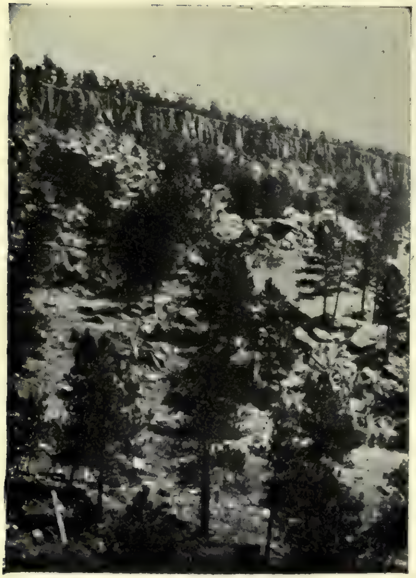

Fig. 168.—A sandstone cliff with talus extending nearly to the cliff top. (Howe, U. S. Geological Survey.)

Talus is found at the base of nearly all steep rocky slopes and naturally it most characteristically occurs where these accumulations often fill the valleys between mountains to a considerable depth, provided there is no stream able to carry away the fragments. As the talus accumulates it extends up the mountain side in a curving slope and indeed "some of the most pleasing curves in mountain topography are those of the talus slope" (Tarr and Martin). Not infrequently the talus becomes covered with vegetation, either through the formation of soil by weathering of talus fragments, or by the soil creep from above. Such soils are in use in Switzerland for pasture and for orchards. Talus soils are usually thin, coarse-textured and droughty and will not be much utilized until other available soils are brought under cultivation; many of them, however, are valuable for forestry

Fig. 169.—Landslide in the foreground. Note the scar on the mountain from which the landslide slipped, Colo. (Howe, U. S. Geological Survey.)

### Landslides and Avalanches

These occur when a mass of rock, soils, and all sorts of debris slide down slopes in areas of a few square rods to areas of acres in extent. Here, again, gravity is the principal factor, but gravity is aided by the steepness of slopes or by thorough soaking of the mantle rock and often by smooth underlying materials like clay, which allows ready sliding of the mass. Fig. 169 shows a landslide and the scar where the mass broke away. Landslides are fortunately rather rare except in a few regions of steep slopes and deep mantle rock, but the movement on a small scale is common. Many hillsides, especially pastures, show small landslides of a few feet, often one above the other like rude stairs. These small, usually unnoticed avalanches, which move but a few feet or a few inches at a time, are of no small importance in the general down slope travel of the land waste. The importance of soil creep combined with head erosion is often overlooked in estimating the importance of soil factors. Millions of acres lying on slopes have their agricultural values largely determined by these processes.

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## CHAPTER X

## GLACIERS AND GLACIATION; GLACIAL SOILS

**Introductory.**—The study of glaciers and their work would be interesting, if only because of the existing glaciers, which are visited by


FIG. 170.—Map showing the glaciated portions of North America and the centers from which the glaciers advanced. (U. S. Geological Survey.)

thousands of tourists. However, when it is remembered that considerable areas of North America and Europe were covered by great glaciers during the Glacial Period, a time very recent, geologically speaking, the study of glaciers acquires added interest and value (Figs. 170 and 171). During this period glaciers of enormous dimensions spread from at least three centers in Canada and extended over the northern half of North America. At the same time northwestern Europe was invaded by the ice. Millions of people in the most productive parts of the earth have their daily lives influenced by the work of extinct glaciers. It is by the study of existing glaciers and their work that we can understand the effects of glaciers which have disappeared.

Fig. 171.—Map showing the parts of Europe affected by continental glaciation (dotted areas). (After J. Geikie.)

## KINDS OF GLACIERS

For convenience of study, glaciers are divided into two types, *mountain glaciers* and *continental glaciers*, terms which are self explanatory, although the types more or less merge into each other and have many features in common

### Mountain Glaciers

When the snow of one winter does not entirely melt during the summer but is added to that of the following winter, there is a gradual accumulation of snow which may result in a glacier. The lower layers are compressed into ice by the weight of the overlying snow and the mass in time begins to spread, and this spreading movement tends to follow the valleys and ravines which lead down the mountain. Thus the glaciers move downward until they reach such a distance that the rate of melting equals or exceeds the rate of ice advance. The distance which a glacier may move in a year or a series of years depends on several factors, among which are changes in the rate of ice movement, the amount of ice and the character of the seasons. The margin of the glacier, therefore, will often change position: it is a common experience in the Alps that a cabin built near a glacier may be destroyed by later advances of the ice. On the northern slopes of the Alps, the glaciers descend much lower than on the southern side because it is colder on the northern side.

In following up a mountain glacier one first crosses the rugged and crevassed ice of the glacier proper, which finally leads to the feeding *snow field* above which provides the material for the ice. Between the snow field and the ice is usually an intermediate zone of compacted and granular snow called the *nevé*.

### Continental Glaciers,

as the name implies, are of great extent and move over ridges, hills and valleys with but little regard to topography. Greenland and Antarctic are at present covered with glaciers of this type; in the Glacial Period, this type was the prevalent one. It is obvious that, because of their inaccessibility, extent and thickness, continental glaciers are difficult to study and have not received such extended and careful study as have mountain glaciers. Much of our knowledge of glaciers has been gained by study of mountain glaciers, but the enormous areas formerly covered by vanished glaciers furnish much information as to their work.

### Conditions of Formation

Two conditions are necessary for the formation and growth of glaciers, namely (1) sufficient snow fall and (2) low temperatures. The one condition has prevented any notable growth of glaciers in many parts of the frigid zone and the other condition, of course, excludes glaciers from hot regions except on high mountains. The most numerous and most familiar glaciers are of the mountain type because of the low temperatures found there. Many mountains are on the verge of supporting glaciers since a winter's snow is scarcely melted during the following summer. It will be clear that glaciers and a glacial period do not necessarily imply an extremely cold climate.

### Movements

The exact nature of ice movement is not well understood, but it is known that ice behaves somewhat like a very stiff fluid. It has been noted that a glacier moves down a valley, a constant proof of which is seen when the baggage of mountain climbers is lost in an ice crevasse and years later reappears at the foot of the glacier; another evidence of a glacier's movement is the progress down valley of large stones on the ice surface. A descending mountain glacier flows somewhat like a stream; in straight reaches the fastest flow is usually near the center and in bends the fastest movement is on the outer side of the bend, as in streams. The rate of movement is ordinarily very slow, usually only a few inches a day, although some exceptionally fast glaciers have been known to move over fifty feet in a day. Ice movement is often accompanied by much crevassing of the glaciers, Fig. 172.

Fig. 172.—Mt. St. Helens, Alaska. Glaciers are descending from the snowfields. (U. S. Geological Survey.)

**The rapidity of glacial movement** varies with several factors. (1) Other things being equal, the deeper the ice the faster it moves. (2) The ice, like water, tends to move fastest over steep slopes. (3) Again, the character of the surface over which the ice moves has some influence; a rough uneven surface offers more resistance than a smooth surface. (4) Ice flows faster when near the freezing point; in other words, the higher the temperature of the ice, provided it does not rise above the freezing point, the faster the ice tends to move. (5) Finally, when ice is heavily loaded with boulders, sand and other debris, it tends to move more slowly. Some of these factors at times cooperate so as to cause notable advance of a glacier and, again, they act in such a fashion as to cause the glacier's front to remain practically stationary.

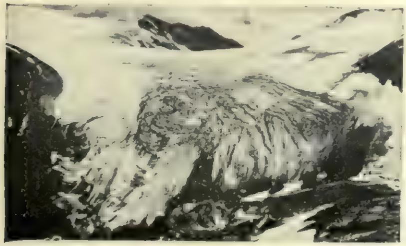

Fig. 173.—Crevassed surface of a glacier, Canada. (Canadian Geological Survey.)

**Ice Advance and Retreat.**—In preceding pages the advance of the ice has been emphasized, for most of the ice erosion is accomplished during the glacier's advance. It will, of course, be understood that the retreat of a glacier is simply a passive melting back of the ice front while the ice advance is an active forward movement. Whether the front of a glacier advances or retreats or remains practically stationary is dependent on the relation of the ice advance to the melting at the ice front. Naturally, in one year or a series of years, if the advance of the ice is greater than the rate of melting, the front of the glacier will advance, but if the melting or evaporation of the ice should increase so that the rate of ice wastage be greater than the rate of advance, the glacier's front will retreat. Practically all glaciers repeatedly advance and retreat and some glaciers advance in one place and retreat in another. The Kewaunee soils which occur in the regions of Lakes Superior and Michigan have been developed by the advances of glaciers over reddish silty clays which have been mixed both in soils and subsoils with gravel, stones and boulders from the glacier.

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## THE WORK OF GLACIERS

**Introductory.**—The work of glaciers is both constructive and destructive. In the ice advance the work is mainly destructive and, in the ice retreat, constructive work predominates. In regions of rugged topography the ice may make but little change in either the major or the minor features but, on the other hand, the minor preglacial features may be nearly obliterated, the drainage deranged and the general aspect of the region much changed, as in some parts of the upper Mississippi Basin. In some places the preglacial soils have scarcely been changed, while in other regions the soils bear little relation to the underlying rocks. It is probably safe to state that, from the viewpoint of soils, there is no other single factor so important in North America as glaciation and the same is true over much of Northern Europe.

### Erosion and Transportation by Glaciers

**Ice Tools.**—Pure ice, like clear water, can accomplish comparatively little erosion but, when armed with boulders, pebbles and sand held

Fig. 174.—Unglaciated hill top above, Virginia. Below, glaciated hill top, Conn. (Conn. Geological Survey.)

in the lower layers, the glacier acquires enormous abrasive power and may scour to depths of scores of feet. Thus armed, the glacier "may be compared to a huge, flexible rasp, fitted down snugly over hills and depressions, and urged slowly forward under enormous pressure." (Chamberlin.) Thousands of exposures of hard rocks show the *scratches* or *striæ* made by stones embedded in the ice and dragged over the rock surfaces, Fig. 175, and stones and pebbles are often ground off when thus held in the ice, Fig. 176, and many small and large rocks that have been carried in the ice show scratches. The striæ on bed rocks, besides being interesting as evidences of glaciation, have much scientific value, because they show the general direction of ice movement.

Fig. 175.—Smoothed and grooved glaciated rock surfaces. (Atwood, U. S. Geological Survey.)

**The vigor of ice erosion** varies with several factors. (1) The faster the ice moves the greater the erosion, other things being equal. (2) It is evident that the thickness of the ice is an important factor, for the thicker the ice the greater pressure upon the surface beneath the glacier and the more effective is the scouring of the underlying rock. (3) Again, the length of time during which a glacier moves over a given region is an important factor. Two rock factors are important. (4) The resistance of rocks varies; obviously a granite will offer more resistance to abrasion than a shale. (5) Then, if stratified rocks dip away from the direction of

Fig. 176.—Stone scratched and smoothed by glaciers.

ice movement, the conditions are more effective for prying and plucking, as shown in Fig. 177. (6) Finally, as in water erosion, the character of the tools is important; hard, angular large rocks are especially effective when embedded in the moving ice and pressed down upon the rock surface beneath the ice.

FIG. 177.—Diagram to illustrate plucking by ice when the rocks dip *away* from the glacier's movement. The arrows show the direction of the ice movement.

In rugged regions like New England, the ice swept away much of the preglacial soil and loose, decayed rock, but even here the glaciers did not remove all the loose materials in all places. On the other hand, in less rugged regions like the plains of the upper Mississippi Basin the glaciers overrode large areas of soils with but little disturbance of them, and often buried soils are found in wells, soils that have been overlain by later glacial deposits.

**Plucking.**—However, even clear ice will pry off or *pluck* projecting pieces of rock, often of great size, and bear them away. This smoothing by plucking is shown in many valley sides. A deep valley produced by stream erosion is likely to have rough sides; spurs project and rock buttresses, often called "chimneys," pinnacles, etc., are often to be found. These forms are either reduced or much modified when a glacier passes through a valley, plucks off the projecting rocks and abrades the walls. Sometimes in a deep valley the lower part of the valley has been smoothed by glaciation while the upper portions, which the glacier did not reach, retain the ruggedness due to ordinary erosion, Fig. 178. Obviously, glacial soils are likely to be bouldery where plucking was prominent. It is usual to find bouldery soils where glaciers have passed over rock ledges, plucked off fragments and strewn them about.

**The Ice Load and its Transportation.**—In contrast with water and wind, glaciers transport all fragments irrespective of size. For the most part the load is acquired and carried in the lower portions of glaciers, especially in continental glaciers. The ice undoubtedly advanced very slowly with but little violent disruption of rock. In approaching and passing over soil and loose rock the ice at times may push some of the unconsolidated materials along near the ice front, but in most cases the ice freezes to these materials and carries them along in a mixture of ice and debris. Indeed, where the heavily loaded basal portions of the great continental glaciers in Greenland have been observed, it is noted

FIG. 178.—Mt. Stephen, with smoothed glaciated lower slopes and rugged unglaciated upper slopes, British Columbia. (Canadian Geological Survey.)

that there is often no sharp distinction between frozen ground and the abundant debris imbedded in the moving ice, Fig. 179. The moving glacier plucks off projecting rock and moves around low hills, sweeping away their soil and loose rocks and adding them to its load; such hills are usually steeper where the ice impinges in its forward movement (*the stoss side*) and more gentle on the opposite side (*the lee side*), Fig. 180.

FIG. 179.—Debris accumulated beneath a continental glacier in Greenland. (U. S. Geological Survey.)

Another source of material for many mountain glaciers, which lie in valleys or are overlooked by cliffs, are the rocks which fall to the surface of the glacier. Such accumulations, during the long journey of the glacier, may become considerable. They naturally accumulate near the sides of the glacier, forming *lateral surface moraines* and, when two or more glaciers unite these moraines are often borne on the surface as long lines of debris, Fig. 181. In addition to the debris near the top and bottom of a glacier, there is more or less debris embedded in the other parts of the glacier. The winds also blow small amounts of dust to the surface of some glaciers. By the process of *ablation*, or melting down of glaciers, the surface debris is sometimes thickened so that, in their lower portions, some glaciers are covered with debris to depths of several feet and this debris may even support a heavy growth of trees.

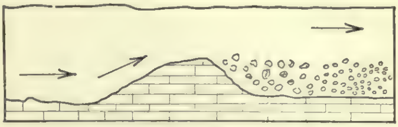

FIG. 180.—Stoss side (left) and lee side (right) of a hill being abraded beneath a glacier. The arrows show the direction of ice movement.

**A glacier acts as a huge mill** grinding its load to smaller and smaller sizes so that much of the material deposited by ancient glaciers is composed of clay. The attrition of pebbles, sand and stones upon each other and upon the rock floor reduces many of them to fine powder so that milky streams flow from many glaciers, the color being due to the fine *rock flour* which the streams carry from beneath the ice. A further agency in comminuting the ice load is the shearing movements in the glacier by which different layers slide over each other and thus rend and grind the load. Some rocks at the top of the glacier may be repeatedly frozen and thawed and thus weakened. It is significant of the rough handling to which the glacier load is subjected that most of the surviving boulders are hard crystalline rocks like granites, quartzites and strong limestones and sandstones. Shales and weak limestones and sandstones are seldom found in glacial debris.

FIG. 181.—Long lines of surface moraines on a glacier, Alaska. (U. S. Geological Survey.)

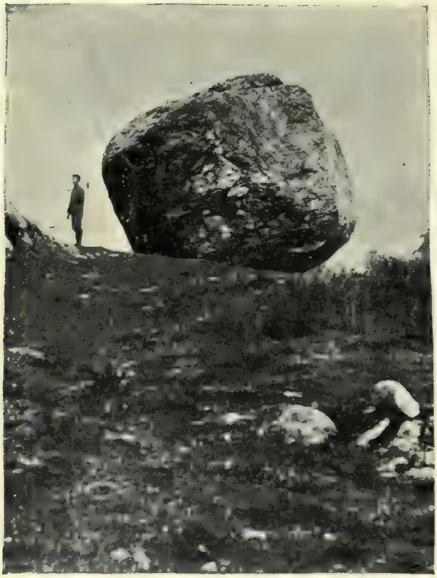

FIG. 182.—Perched boulder of quartzite resting on marble; an erratic. (Dale, U. S. Geological Survey.)

**Erratics** are foreign boulders which have been taken up or plucked and then carried and deposited by the ice; they include weak boulders, which have been carried only a short distance, but erratics for the most part are strong rocks which have endured the wear and tear of the journey of the ice. In the Middle West these boulders of granite, diorite and other rocks attract considerable attention, for they are so different from the underlying rocks; they are frequently used for building materials. In New England they are locally so numerous that clearing them away is an important agricultural problem. Stone fences, Fig. 183, are frequent in areas with numerous erratics. Geologically, erratics are of great value in tracing movements of the ice. "Perched boulders," "balanced rocks," "rocking stones" are expressive terms for some erratics.

FIG. 183.—Stone fences of glacial rocks, Wis. (Alden, U. S. Geological Survey.)

## GLACIAL DEPOSITION

Fortunately for mankind in the glaciated regions, much of the ice-eroded surfaces has been recovered by the ice as the glaciers retreated. In places this covering is very thin and, again, it is hundreds of feet in thickness. These deposited materials are naturally of great agricultural interest, since they furnish the soils of the glaciated regions.

## The Drift

Drift is the general term applied to all glacial debris, a term that was used when it was believed that glacial materials were deposited by water. The drift may be stratified when it is due largely to water work or unstratified when due largely to ice deposition. *Till* is the term applied to the heterogeneous mass of clay, pebbles, sand and boulders deposited by the ice, Fig. 184; the more descriptive term, *boulder clay*, is often used for this unassorted material. The most characteristic feature of the drift is its heterogeneity. In a small area one may find stratified and unstratified materials; variations in size from boulders through gravel and sand to clay together with rocks of many origins, different compositions and both fresh and weathered rocks. In short, the drift as a whole is that unassorted, heterogenous mass of rocks, clay gravel, etc., with clay usually predominating that one would expect from such an agent as ice. It should, however, be remembered that considerable areas of local drift are fairly homogeneous for some distances and some glacial soils are as homogeneous as many residual soils, but, as compared with alluvial soils and with most residual soils, glacial materials and soils are decidedly changeable. The heterogeneity of glacial materials arises from the complexity of their origin, the variety of the ice load and the different processes involved in the formation of drift.

FIG. 184.—Glacial till lying on solid rock, N. J. (U. S. Geological Survey.)

**The thickness** of the drift shows an expectable variation from zero to scores or hundreds of feet, the thickness varying with the amount originally deposited, the erosion subsequent to the deposition and to the preglacial topography, Fig. 185. It is not unusual in the upper Misisssippi Basin for large areas to be so thickly covered with drift that the underlying rock is not exposed even in the deepest valleys. The statement may be made, although there are many exceptions, that in rugged regions like New England the drift is thin, and in smooth regions like the plains of the upper Mississippi Basin it is thick. In general, some till is found wherever there was ice, but the stratified drift was carried beyond the glaciers so that, as a result, the area of drift is larger than the area covered by the ice.

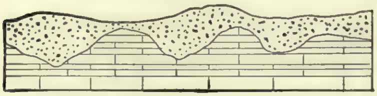

FIG. 185.—Diagram to illustrate variation of drift thickness due to buried hills and valleys.

**Composition of Drift.**—The variations both of materials and of their arrangement in the drift are especially characteristic. In a single exposure one may often find variations in size from boulders to clay, but even the most stony till usually contains considerable percentages of fine materials. Two examples will show this variation. From a careful study of the somewhat stony drift around Boston, Cros by has estimated that the clay or rather rock flour constitute, about 10 per cent of the drift while nearly 50 per cent is composed of sand. In contrast, Leverett found that some of the till in Illinois contains over 90 per cent of clay.

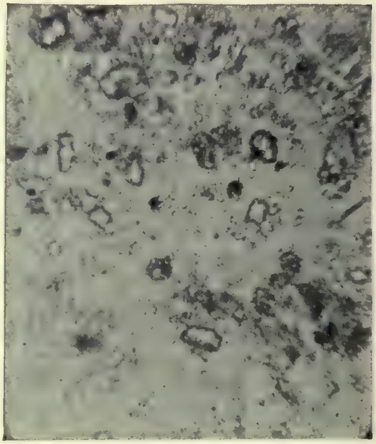

FIG. 186.—Glacial clay. Note the angular bits of rock scattered through the clay (much magnified).

The size of the different constituents of till is dependent on many factors. Obviously the resistance of the rocks determines to a considerable degree their endurance of the wear and tear of glacial transportation so that the boulders and much of the smaller materials are granite, quartzite and other strong rocks that may be carried hundreds of miles. For example, quartzite boulders, locally called "lost rocks," are rather common in the drift on northern Missouri, and these have been transported several hundred miles with but little evidence of wear.

Most shales are so weak that they are for the most part broken up when they are first acquired by the ice and are rarely transported for any considerable distance except as clay, silt and small fragments. Many schists and some gneisses, sandstones and limestones are also ground into rock flour by the ice.

It should always be remembered that glacial clay and residual clay are different; they differ both chemically and physically. Glacial clays are ground-up rocks for the most part although the ice of course picks up and transports residual clays, while, on the other hand, residual clays are the insoluble clays left after long weathering. Glacial clays under the microscope often show many minute angular fragments of rocks and minerals, usually fairly fresh, while residual clays usually show weathered and more or less rounded minerals, usually much decomposed, Fig. 186. Under the same conditions drift is fresher, less weathered and less leached than the same kinds of residual materials, as the following table illustrates:[1]

| | 1 (residua' clay) % | 2 (Glacial lake clay). % |
|---|---|---|
| Silica | 62.11 | 44.51 |
| Alumina | 16.96 | 8.00 |
| Phosphoric acid | 00.025 | 00.09 |
| Iron oxides | 7.65 | 3.19 |
| Lime (CaO) | .90 | 13.74 |
| Magnesia | .90 | 7.42 |
| Potash | 1.22 | 2.48 |
| Soda | 1.82 | .88 |
| Carbon dioxide | .20 | 17.11 |

[1] Chamberlin and Salisbury, 6th Annual Report, U. S. Geological Survey, page 250.

Number 1 is a composite sample of residual clays and Number 2 includes samples of glacial lake clays. The samples are not to be regarded as characteristic except that they show clearly the greater leaching of the residual clays. The variety of materials in the drift is readily understood when it is remembered that the glaciers carried preglacial soil and subsoil, weathered and fresh rocks, alluvial materials and not infrequently even older glacial materials. Furthermore, all these were subjected to the destructive processes due to the ice acquiring its load and to the wear of the load during transit.

## Moraines

Glaciers deposit mainly in two places, beneath the glacier and at or near its margin. Ice, like water, may become overloaded with debris and be compelled to deposit some of its load beneath the glacier as it advances. Such deposition beneath the ice occurs only locally and, furthermore, such deposits are exposed to the erosion of the ice following after; in fact these deposits beneath the ice are subject to repeated erosion and deposition. Such deposits are termed *ground moraine;* on the whole they are not extensive. In places this ground moraine constitutes the subsoil and is usually known as "hard pan"; it is often much compacted by the pressure of the overriding ice and must be removed by dynamiting when wells are dug through it.

## Terminal Moraines

Conditions for deposition are exceptionally favorable when the margin of the ice becomes relatively stationary because of melting or evaporation. The ice under such conditions is inactive and sluggish, less able to carry its load and more likely to deposit debris beneath the glacier. It is of course obvious that melting ice at once drops its load. It has been noted before that, even when the glacier as a whole is advancing, it is subject to halts, retreats and readvances and the same is true when it is retreating. When the rate of ice advance is about balanced by the rate of melting, the drift is deposited near the margin and forms the *terminal moraine.* If the ice front is nearly stationary for a long time, a well-marked ridge would be built, more or less coinciding with the front of the glacier; in a comparatively few places wall-like or ridge-like terminal moraines have been built, but they are on the whole exceptional. However, the usual oscillations of the ice front scatter the drift over a zone several miles in width so that the usual terminal moraine is a low, broad ridge composed of drift and it may be indistinct in places. Terminal moraines are characteristically composed of till, but it is readily apparent that they also contain much stratified drift since they were usually deposited in a zone of melting ice.

**The topography** of a terminal moraine is usually somewhat characteristic. Typically it consists of small rounded hills and adjacent depressions in a disorderly arrangement, Fig. 187. Many of the depressions are kettle-like in shape and consequently they are often locally called "kettle holes"; where these depressions occur in till they often contain water, and dozens of small ponds often map a terminal moraine. Again a terminal moraine is often composed largely of low interlocking ridges of drift. The following terms are somewhat descriptive of this peculiar topography and are in common use: "sag and swell"; "knob and basin"; "hummocky"; "hummocks and hollows." In places the surface is decidedly hilly but more commonly it consists of gentle swells with low interlying depressions, all giving an undulating surface.

It is not always easy to explain this topography. In places the ice carried and deposited a heavier load and here would naturally be an elevation. Ice blocks become detached, covered with debris and, upon melting, may leave a depression. Then the ice advancing and retreating in minor movements, pushing the old drifts and depositing new drift, would account for some of the peculiar topography.

FIG. 187.—Terminal moraine on a valley side, N. Y. (Tarr, U. S. Geological Survey.)

**Recessional Moraines.**—It will be remembered that both the ice advance and the ice retreat were characterized by halts and at each prolonged halt the glacier built a terminal moraine. The moraines built by the advancing ice were overridden and for the most part, obliterated. On the other hand, as the ice front retreated, it built moraines during the various halts which are often termed *recessional moraines,* which are in all respects like terminal moraines. The glacier front, and consequently, the terminal moraine, were almost never straight, but in lobes, and this arrangement is especially emphasized where lowlands and valleys extended in the general direction of ice movement, the lobes of ice extending down valleys. This is well shown in the great reach of country extending from Wisconsin to New York, where the lobes extended in a southerly direction along the Great Lake depressions, Fig. 188. The same features are seen in the Allegheny Plateau of southern New York, where many recessional moraines are ranged in lobes one behind

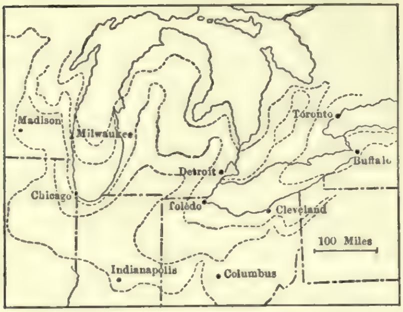


FIG. 188.—The dotted lines mark successive positions of the ice in its retreat. (After Leverett, U. S. Geological Survey.)

the other in the north-south valleys, while the moraines are very faint on the uplands.

**The soils of terminal and recessional moraines** are varied in composition, texture and drainage, but texture and drainage show the greatest variation in short distances. The water derived from the melting ice at the glacier's margin naturally produced variations in texture so that small areas of sandy, heavy and medium textures are often closely intermingled. On the other hand, the surface drainage is dependent on the topography, which varies from well-drained hillocks to the undrained sags.

Fig. 189 shows the varied soils of a terminal moraine in southeastern Michigan. The clay loams are derived from till which contains some sand while the gravelly and sand-loams are derived from water laid materials, the one from rapid and the other from moderate currents. The muck soils and the lakes occupy low undrained depressions. Not all soils of terminal and recessional moraines are so complicated, but usually these soils are more complicated than the soils of other glacial features.


FIG. 189.—Morainic soils, Mich. (Data after U. S. Bureau of Soils.)

## The Ground Moraine

When a glacier recedes, its debris, instead of being concentrated in a terminal moraine, is scattered over the surface left by the retreating ice. Such a deposit is termed the *ground moraine*, a term, it will be remembered, that is also applied to the far less important deposits beneath the advancing glacier. The ground moraine is by far the most important and widespread deposit of the great continental glaciers, at least from an agricultural point of view. It is characteristically composed for the most part of till, but it also contains varying amounts of stratified drift. In general the terminal moraine contains a higher percentage of boulders and much more intermingled stratified drift than the ground moraine. The topography of the ground moraine is commonly smooth or gently rolling, Fig. 190, except where modified by later erosion. In places, as in north-central Ohio, it is so smooth as to be a typical plain; the glacial prairies of Illinois, Iowa and northern Missouri are largely ground moraine. Such a youthful topography is likely to be poorly drained both because of the depressions in which

FIG. 190.—Ground moraine, Wis. (W. J. Geib, U. S. Soil Survey.)

water may stand and because the streams are not yet organized for effective drainage and erosion Lakes, ponds and swamps are rather characteristic of the ground moraine, although they are nearly absent on some of the older drifts where streams are well established and on some of the well-drained portions of the newer drift. A ground and terminal moraine are shown in Fig. 196.

**The soils of ground moraines** are less variable than those of terminal moraines and the ground moraine soils tend towards clays, clay loams and silt loams rather than the lighter-textured soils. Compared with terminal recessional moraines, these soils are relatively free from stones. The relatively level topography produces somewhat poor drainage so that many thousand miles of tile drainage have been installed on the ground moraines of the Middle West. The level surface with the resulting slow drainage has also promoted an accumulation of humus in these soils. Many of the more shallow depressions are occupied by muck soils.

### Drumlins

These are hills that are sometimes associated with the ground moraine. Their ground plan is in general somewhat ovoid, their longer axis lies parallel to the general direction of ice movement and their steeper slopes are generally to the northward, from which direction the ice advanced. Beyond the fact that drumlins are distinctively a glacial product, their origin is as yet undecided. They usually occur in groups

FIG. 191.—"Side" View of a Drumlin, Wis. (Alden, U. S. Geological Survey.)

and are often locally called "whalebacks." Drumlins are composed largely of till and they contain but little stratified drift. Their soils are rather heavy and naturally subject to erosion because of their fine texture and the steep slopes on which they lie. Areas between drumlins usually have poor drainage and often the soils contain considerable humus; in some parts of New York such soils have been used for celery, peppermint and other truck crops. Drumlins, themselves, because of their steep slopes, are usually left in pasture.

### *Relations of Drift and Glacial Soils to Local Formations*

**Introductory.**—While it is probably true that each square mile of drift contains materials from all the surface over which the contributing ice has passed, yet, as a whole, the drift shows more or less close relations to the adjacent underlying rocks. This relation is usually closer where the drift is thin rather than thick; indeed, where the drift is very thick there is often no apparent relation whatever. It is estimated by Chamberlin and Salisbury that, on the whole, 75 per cent of the drift has not been carried more than 50 miles. Shaler estimates that, in the Narragansett Basin of southern Massachusetts and eastern Rhode Island, about 80 per cent of the drift is local and Alden, working in eastern Wisconsin, made a careful study showing that at least 87 per cent of the drift is local. These estimates made after long study clearly show that usually there is a close relation between the drift and the neighboring underlying rocks.

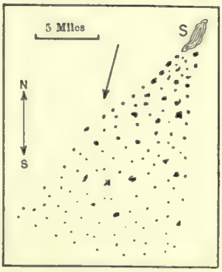

FIG. 192.—Fan-like glacial debris from outcrop ($S$). (Salisbury, N. J. Geological Survey.)

The local origin of some drift is illustrated by Fig. 192. A small area ($S$) in northern New Jersey of a distinctive rock (syenite) has been thoroughly eroded by the ice and the debris has been scattered over a fan-like area for several square miles. It is found that these characteristic rocks are smaller, more scattered and less plentiful with increasing distance from the parent outcrop ($S$). If we imagine not one outcrop which is eroded by the moving ice, but thousands, it is clear that much of the drift must be local. Many factors, of course, such as the resistance of the rock and the vigor of erosion are influential in determining the proportion of local drift in a given locality.

**Influence of Local Rocks on Glacial Soils.**—The local bed rocks usually show more or less influence on glacial soils. Glacial soils overlying sandstones are likely to be sandy or loams; those overlying shales are likely to be heavy; soils overlying limestones, in contrast with most residual limestone soils, are very often highly calcareous, so much so that subsoils and often soils will effervesce with acid; glacial soils overlying granites are likely to contain many granite fragments, they are often somewhat stony and usually show a somewhat high content of potash. Glacial soils sometimes resemble true residual soils and this is especially true of heavy glacial soils derived from shales. Stony glacial soils show a close relation to the character of the local bed rock over which the glaciers passed and to the distance the ice load has been transported. If the underlying or adjacent rocks are resistant as, for example, granites or quartzites, the till and soil are likely to be stony.

The influence of bed rock on glacial soils is especially noticeable when the bed rock is somewhat distinctive, especially in color. This is well shown in the Connecticut Valley of Massachusetts and Connecticut where the underlying red shales and sandstones impart a reddish color to much of the drift and often to the subsoils. Another example is found in the Volusia soils, which are widespread and somewhat characteristic of the northern portions of the Allegheny Plateau. The underlying rocks are largely of shales and sandstones. Glaciation in this hilly region was relatively ineffective in changing the character of the soils and the Volusia soils differ but little from residual soils on the same formations further south beyond the limits of glaciation.

An excellent study of soil values as determined by the influence of local rock on drift and soils has been made by Whitbeck.[1] In southeastern Wisconsin there is a large area not covered with drift and adjoining this are areas in which the drift is underlain by sandstone and limestone with the usual result that the drift and its derived soils are markedly influenced by local bed rocks. Some of his conclusions are as follows:

| | Driftless area. | | Glaciated area. | |
|---|---|---|---|---|
| | Sandstone. | Limestone. | Sandstone. | Limestone. |
| Per cent of improved land | 37.2 | 60.5 | 48.2 | 70.3 |
| Average values of all crops per square mile | $1,968 | $2,690 | $2,776 | $3,828 |

"The yield of corn oats and barley was a little higher per acre in the limestone belt but only a little higher in the drift soil than in the driftless. In the sandstone belt the difference is more pronounced. In each of these crops, the average yield per acre is distinctly higher in the drift soil, averaging in the three crops practically 33⅓ per cent. The residual limestone soil of Wisconsin, like that of Kentucky or Virginia, is inherently rich and would not be much improved by the addition of the drift. The residual sandstone soil is inherently sterile and would be materially improved by the addition of drift which came from the limestone area on the east."

An interesting area in northeastern Wisconsin illustrates a relation of glacial soils to underlying granite, sandstone and limestone, Fig. 193. The soils above the granites are somewhat stony and sandy with many scattered granite boulders and rocks. The magnesian limestone contains considerable sand and the soil above this and above the sandstone as well is a fine sandy loam but, as one would expect, the

[1] Aspects of the Glaciation of Wisconsin, R. H. Whitbeck, Annals of the Association of American Geographers, Vol. 3, 1913.

soils over the limestone contain many limestone boulders and fragments. The drift above the Trenton limestone contains a considerable admixture of materials from the granite and sandstone areas to the northward, but the soil is a somewhat calcareous sandy loam and the subsoil is largely composed of limestone debris.

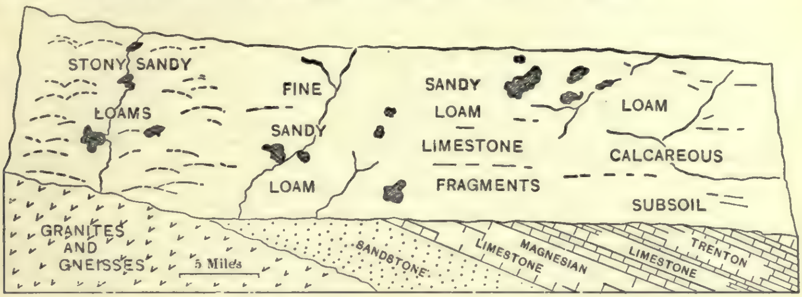


FIG. 193.—Diagram to illustrate some relations between glacial soils and the underlying rocks in Wisconsin. (Data after U. S. Bureau of Soils.)

**Ice Movement and Rock Strike.**—The relation between the direction of ice movement and the direction of rock outcrop (Strike, page 58) is important. When a glacier moves for a considerable distance *along* a rock outcrop, the ice load is necessarily derived largely from the outcrop, the drift will contain much material from the outcrop and the soils will considerably resemble residual soils from this outcrop. On the other hand, when a glacier moves *across* several rock outcrops, the drift will contain varying amounts from the different outcrops and the resultant soils are likely to be a mixture of materials of far greater complexity than in the other instance.

A case in point is shown in Fig. 194. This region in northwestern New Jersey is somewhat mountainous; the rocks are folded and in consequence there is a suc-

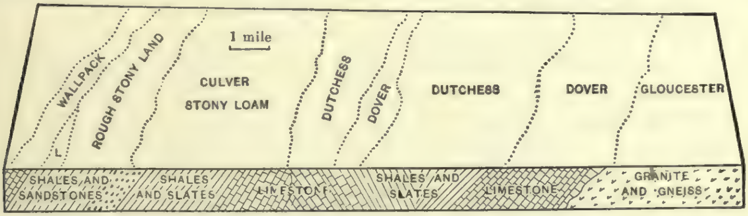


FIG. 194.—Generalized diagram to illustrate the relations of rocks and soils when the glacial movement was parallel to the rock outcrops. (Data after U. S. Bureau of Soils.)

cession of ridges and valleys (see Fig. 57). The general ice movement was from northeast to southwest roughly parallel with the rock outcrops with the result that the till and its derived soils show a banded arrangement such as we find in residual soils from folded rocks (Fig. 49). In the eastern belt the Gloucester soil series is derived largely from gneisses; it is sandy and likely to contain considerable undecomposed mica and gneissic rocks of varying size. The limestones give a calcareous till from which are derived the Dover soils which are mainly loams often containing limestone fragments of various sizes. The Dutchess soils are derived largely from till which, for the most part, was gathered from shales and slates; slate fragments are very common in the drift which is usually rather thick. The Culver stony loam is derived from a somewhat mixed till; the rock fragments and boulders are clearly derived from the conglomerate and sandstone of the adjacent rock belt to the westward and the finer materials of the till are derived from the immediately underlying shales and slates and from a sandstone belt to the westward. Much of this belt is rough stony land.

As a whole the topography of this region is rough, ranging from mountain ridges to hills. The ice in most of the region eroded the preglacial soil and failed to replace its equivalent and, furthermore, the hilly topography has favored erosion by which the glacial soils have been in part washed away since they were deposited. The Wallpack soils which form the westernmost soil belt show another not uncommon feature of glacial soils in hilly regions. The soils are in part derived from limestone, sandstone and shale till, but some are true residual soils, being derived from post glacial weathering of exposed weak rocks. An examination of the diagram shows that soil boundaries and rock boundaries are far from coinciding, much less coincidence, in fact, than we find in residual soils. There were different minor ice movements sometimes at angles to the main glacial movement, movements which carried the debris across the formations.

## FLUVIO-GLACIAL WORK

For convenience of discussion we have considered the work of ice by itself without reference to the water which was usually associated with the glaciers even in their advance and which was, of course, a very prominent factor when the ice was melting back. It has been seen that the advancing continental glaciers were subject to halts and even minor retreats due to the melting of the ice. At such times the water from the melting ice made stratified deposits most of which were destroyed when the glacier resumed its main advance. Nearly all drift contains " pockets " of stratified materials which were formed by water derived from local melting of the ice. But the greatest floods of water coming from melting ice came when the glaciers made long halts or were in retreat when enormous quantities of water were released, waters which took up and redeposited the drift. Such deposits made by water from melting glaciers are termed *fluvio-glacial deposits*. They are especially important from the standpoint of soils because they are usually surface materials from which large areas of soils are derived.

Fluvio-glacial soils are characteristically coarse-textured because they are usually deposited by rather swift currents with the result that gravelly and sandy soils are rather characteristic of deposits.

## Outwash Plains

When a glacier halts on a plain sloping away from the ice, the waters from the melting ice spread over the plain, cover it with their deposits and build an *outwash plain.* Usually the water from the ice escapes in streams flowing through and away from the terminal moraine rather than as a broad sheet of water and these streams each build low alluvial fans which coalesce into a compound fan, the whole series of fans making the outwash plain. Fig. 195 shows a stream flowing from a glacier in Alaska and building a low fan; during the glacial period thousands of these streams built the wide stretches of outwash plains.

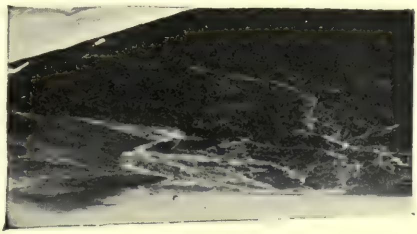

Fig. 195.—Glacial streams building alluvial fans, Alaska. (Tarr, U. S. Geological Survey.)

The swift, heavily laden waters built steeper slopes near the terminal moraines and also here deposited their heavier loads, often gravels mixed with sand. Farther away from the moraine the deposits were built into more gentle slopes and the materials deposited were finer. A typical outwash plain has a very flat surface in the outer portions away from the moraine, so level, indeed, that such portions are often locally called " prairies." Nearer the moraine the slopes rise and the topography is likely to become " ridgy." Not infrequently the surface is interrupted by depressions and ponds where the waters built debris about masses of ice which had become detached from the glacier's front and this ice upon melting left depressions. Usually somewhat faint, shallow valleys, now often unoccupied by streams, show the old courses of streams flowing from the ice. Fig. 196 shows relations between the outwash plain and terminal moraine.

**The soils** of outwash plains usually show two characteristics. They are typically coarse-textured sands, sandy loams and gravelly sandy loams being frequent types. Again these soils usually show a gradation from coarse-textured soils near the moraine to fine-textured soils near

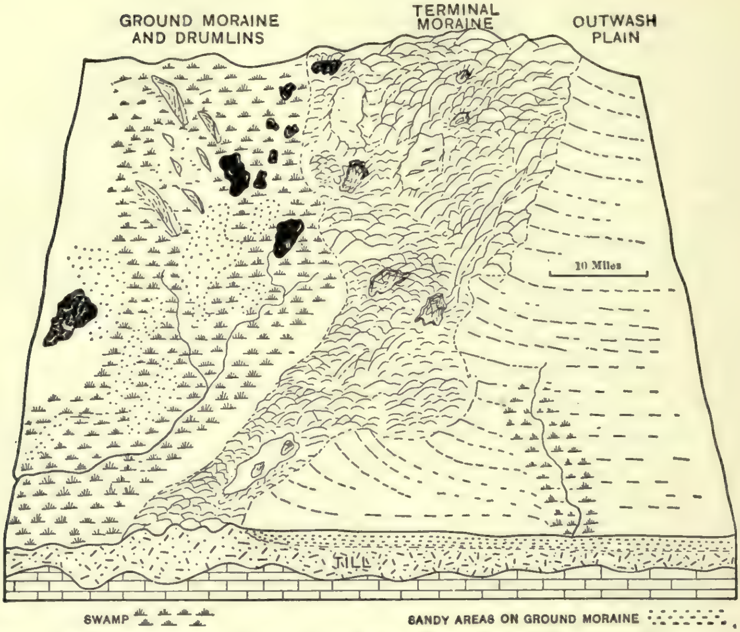


FIG. 196.—Diagram showing glacial features in an area in southeastern Wisconsin. (Data after Alden, U. S. Geological Survey.)

FIG. 197.—Looking across an outwash plain toward the terminal moraine in the background, Maine. The section is shown in Fig. 252. (U. S. Geological Survey.)

the border of the outwash plain. Drainage, particularly subsoil drainage, is usually good because of the sandy texture of the soils. Indeed, the materials are often so coarse near the moraine that the water table stands so low that nothing but deep-rooted trees can reach moisture. Outwash plains are often fairly well mapped by crops; the upper gravelly portions being in orchards or forests, the middle coarse sandy portions being in truck and corn and the lower fine sandy loam soils are often in wheat and corn. The composition of these soils varies, of course, with the materials furnished to the waters from the melting ice, but they are usually siliceous.

The southern part of Long Island includes one of the most extensive outwash plains in North America. The surface features of Long Island are almost entirely due to constructive glaciation; the Island consists essentially of two terminal moraines at the north separated by a narrow discontinuous outwash plain, and at the south is a wide outwash plain extending for 100 miles and forming the southern part of Long Island,

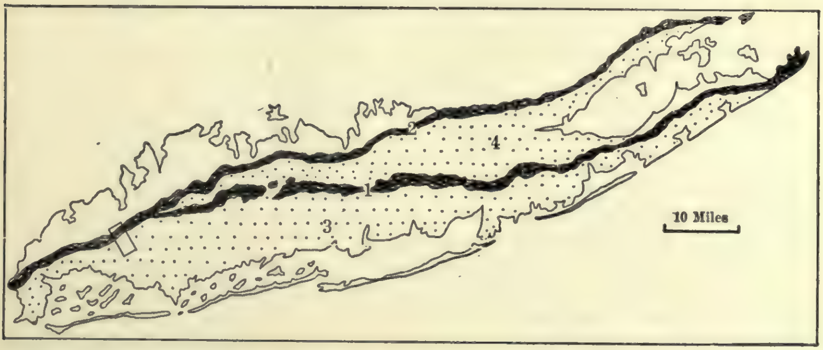


FIG. 198.—Sketch map of Long Island, N. Y., showing the two terminal moraines (1 and 2) and the two outwash plains (3 and 4). The rectangle in the western part indicates the area shown in Fig. 199.

Fig. 198. The glacier halted and built the southernmost terminal moraine (No. 1 in Fig. 198) and the water from the melting ice built most of the large outwash plain (No. 3). After this well-defined terminal moraine was built, a change of conditions caused the ice front to melt back over much of the Island except in the extreme western part. This retreat continued for several miles when again the ice front halted and built the second moraine (No. 2). When the outwash water built the second outwash plain (No. 4) but a part of the water escaped through openings in the first terminal moraine (No. 1) and added some

materials to the first outwash plain (No. 3). The convergence of the terminal moraine in the western part of the Island indicates that here, for some reason not apparent, the ice front did not retreat, but maintained its position, while farther east the ice front retreated to the position of the second terminal moraine. Such inequalities in retreat are the rule and not the exception and they add to the complexities of glacial studies.

Fig. 199 shows a portion of the first terminal moraine and the outwash plain to the southward which are figured in Fig. 198. The surface of the moraine is hilly to rolling without any definite drainage lines except the more or less indistinct valleys where outwash waters cut through portions of the moraine that was already built. Depressions, some containing water and some dry, show where ice blocks were wholly or partly covered with debris and upon melting left depressions. The till contains considerable stratified materials deposited by water and there are many boulders of granite and similar rocks which the ice carried from New England. There is in the till a considerable amount of gravel and sand which is largely due to the underlying materials which were in part taken up and incorporated in the till. The soils of the terminal moraine here are largely loams and sandy loams although locally there are stony areas. The hills are naturally well drained, but the depressions are poorly drained except where the materials are so sandy or gravelly that the rainfall and inflow are carried away by subsurface drainage.

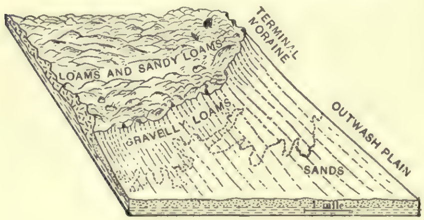


Fig. 199.—Diagram to illustrate the relations of soils to a terminal moraine and an outwash plain in western Long Island. (Data from U. S. Bureau of Soils.)

The outwash plain is seen sloping away from the terminal moraine with steeper slopes nearer the moraine. The diagram does not show the many alluvial fans, some separate but many coalesced, which in many places extend outward from the moraine. In the upper zone is a belt of gravelly loams with a somewhat lobate margin which was deposited by relatively swift water. This belt grades southward into the very gentle slopes of the lower outwash plain where the soils are very sandy. In this part, when the outwash plain was being built, the streams were slow and often divided and subdivided into somewhat sluggish streamlets which carried fine materials.

## Valley Train

On the other hand, when the outwash water from melting ice is spread over a valley as the glacier melts back, the *valley train* is built; an outwash plain is built when the ice halts for some time, but the valley train is the fluvio glacial material scattered over a region as a glacier retreats. In a region traversed by valleys the ice is thickest in valleys and consequently the principal deposits in the form of terminal moraines, outwash plains and valley trains usually occur in valleys which slope away from the ice front. As the glacier melts back, the outwash waters, usually heavily laden with sediment, flow down the valley, often filling it with gravel and sand to depths of scores of feet. Just as outwash plains are analogous to alluvial fans, so valley train may be regarded as a special type of alluvial plain, usually composed of coarser materials than a flood plain and lacking the front and back lands of flood plains.

Valley trains often extend far beyond the farthest limits of glaciation, whither they were carried by outwash waters. In many cases later streams have frequently cut channels in valley trains, leaving them as terraces above the present streams. The glaciers in valleys as elsewhere halted and built terminal moraines with accompanying outwash plains and in fact there are all gradations between outwash plains and valley trains. Soils of valley trains are usually sandy or gravelly and of irregular arrangement. The valley train in some places is so thin that underlying till constitutes a "hard pan" and wells often penetrate to the usually underlying till.

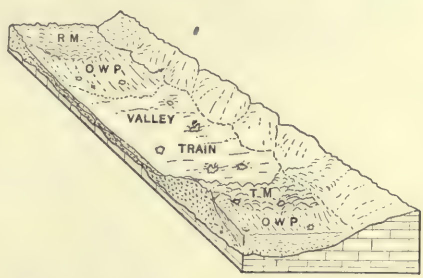


FIG. 200.—Diagram to illustrate the formation of a terminal moraine (*TM*), a recessional moraine (*RM*), outwash plains (*OWP*), and valley train.

A somewhat ideal illustration of these features is seen in Fig. 200. The ice front halted and built the first terminal moraine (*TM*) and the outwash water built the outwash plain (*OWP*). Then the ice front melted back a considerable distance without any notable halts and the escaping waters built up the valley to a fairly level plain, the valley train. Another long halt resulted in another moraine (recessional moraine, *RM*) and another outwash plain (*OWP*).

## Kames and Eskers

Two other fluvio-glacial forms are interesting, although not important from a standpoint of soils. Under some conditions, heavily laden glacial streams sometimes built hills of gravel which are called *kames*. *Eskers* are winding ridges of sand and gravel (Fig. 201); they are often locally called "serpent ridges." Their materials are usually irregularly stratified. In some cases they are several miles in length, although they are seldom continuous for long distances. Eskers are evidently the beds of streams which flowed in or beneath the ice and when the ice melted these winding stream beds were left. Both kames and eskers make coarse-textured, droughty and infertile soils, usually uncultivated,

FIG. 201.—An esker in Michigan. It curves from right to left. (Russell, U. S. Geological Survey.)

but in some cases they are in forest. Locally they are important sources of gravel and sand.

**Typical Area.**—Fig. 196, which shows an occurrence of ground moraine, terminal moraine and outwash plain together with some other glacial features, will afford a brief review of glacial work. The terminal moraine is here termed the " kettle moraine " because of the hundreds of kettle-like depressions. The topography is extremely complex; parallel and diverging low ridges, depressions, occasional flat-topped hills and hundreds of large and small irregularly shaped hills " combine to form a wilderness of humps and hollows " (Alden). The ground moraine has a flat to undulating surface with drainage so poor that much of the area is swampy. Shallow depressions are occupied by lakes, many of which have no outlets. Other features often associated with the ground moraine in this and many other regions are the drumlins, the low ovate hills which are seen rising above the surface in the northwestern part of the area. The outwash plain here shows the usual steeper slopes near the terminal moraine with very gentle slopes farther to the east.

The drift in this region is gravelly and sandy with frequent boulders and comparatively little clay. As a result the soils of the terminal and ground moraines are, as a whole, coarse textured. Drainage on the terminal moraine, both surface and subsurface, is excessive because of the sandy and gravelly soils and much of this feature is non-agricultural land. On the other hand, while the soils of the ground moraine are sandy, the level surface and slow drainage have produced such an accumulation of humus and other vegetable matter that the soils are of a somewhat "stiff" character; the poor drainage has also led to an accumulation of peat in places. Many of the patches of sandy soils seen in the ground moraine are due to local outwash from the glacier as it was retreating. The soils of the outwash plain are loams for the most part with beds of sand and gravel often underlying the subsoil. The drainage is good and these soils are fairly productive. It will, of course, be noted that there are many contrasts between the soils in this area and those shown in Fig. 199 (Long Island) and these contrasts emphasize the fact of soil variability in glacial materials.

Fig. 202.—Diagram to illustrate the smoothing of a rough preglacial topography (left) and roughening of a smooth preglacial topography (right).

## Topographic and Drainage Changes Due to Glaciation

The changes due to glaciation in soil composition and in topography and drainage have been noted to some extent. Topography and drainage, as affected by glaciation, deserve further consideration because they are very important soil factors. Topographic changes, due to glaciation, include both destructive and constructive changes, both erosion and deposition. A somewhat hilly region may be smoothed both by erosion and by deposition, while a level region may be so covered by forms of drift such as drumlins and terminal moraines, for instance, as to have a rougher topography, Fig. 202. An area in southeastern Wisconsin is illustrative, Fig. 203. The diagram shows a preglacial area with a somewhat rugged, mature topography which was completely covered with drift and the former topography entirely obliterated. The present youthful topography is rather flat except where it is crossed by a terminal moraine. The present Rock River flows a little west of its old valley while Turtle Creek flows across the former preglacial divide.

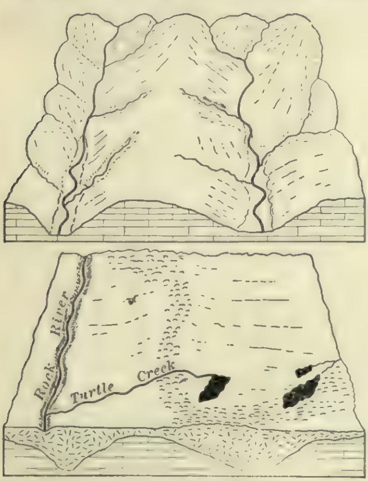


Fig. 203.—An area in Wisconsin. Upper diagram, probable preglacial topography and drainage; lower diagram, present features. (Data after Alden, U. S. Geological Survey.)

FIG. 204.—Unglaciated valley, Utah. (Atwood, U. S. Geological Survey.)

FIG. 205.—Glaciated valley, Utah. (Atwood, U. S. Geological Survey.)

## Features of Erosion

The erosive effects of ice on plains and other somewhat level surfaces appear to be slight; indeed there are large areas where the continental glaciers failed to remove even the soils, for buried soils are often

FIG. 206.—Distant view (upper) and close view (lower) of a cirque, Canada. (Canadian Geological Survey.)

found beneath later glacial deposits, Fig. 214. However, when the flow of thick ice is concentrated in valleys, there is often great erosion. The valley sides are smoothed and if the valley is V-shaped it is likely to be worn to a U-shaped section, Figs. 204 and 205. Valleys are often deepened so that tributary valleys are left above the main valley and form the *hanging valleys* so often found in glaciated regions. *Fiords* are glaciated valleys near a coast into which the sea has been allowed to enter by a sinking of the coast; they are thus due to a combination of coastal depression and to glacial erosion. *Cirques* are ampitheater-like openings often found at the heads of glaciated mountain valleys, Fig. 206. These erosion features are most characteristic of valley glaciers although they are by no means confined to them.

Continental glaciers, because of their great mass of ice and their longer journeys, have more opportunity for acquiring loads and are in consequence more important as depositing agents than valley glaciers. While it is true that some terminal moraines are hilly, yet in the main the topography due to continental glaciation is youthful and the drainage immature and, on the whole, a region covered with drift is usually smoother than before glaciation.

## Drainage Changes

These changes due to glaciation are mainly caused by deposition, for, while ice erosion effected minor changes in drainage lines, the main changes have been due to the blocking of old drainage lines by deposition of drift. In many preglacial stream valleys the drift was deposited in places so as to turn the stream out of its former course, and in fact entire stream valleys were sometimes filled with such thick drift deposits that, when the ice withdrew, the stream was forced to take an entirely new course, Fig. 203. Such streams are termed *diverted streams*. A fine example is seen in southeastern Iowa where the Mississippi River flows for the most part in a broad valley, but near Keokuk the valley narrows for about 25 miles and then widens to its former width, Fig. 207; a few miles west the old river valley has been filled with drift which so completely blocked the drainage that the Mississippi was compelled to cut the present new valley. Such features are of small direct agricultural importance, but are of great economic importance, since many of the great water-power sites like those at Keokuk, Minneapolis and Rochester are due to diverted streams. River

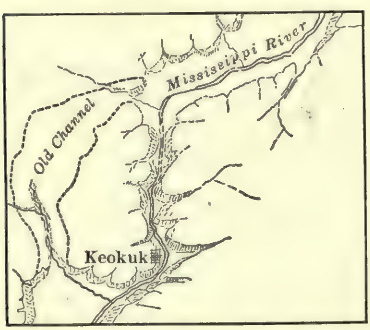


Fig. 207.—Preglacial and postglacial valleys of the Mississippi in southeastern Iowa. The buried preglacial valley is indicated by dotted lines.

valleys have even been so filled with drift that, upon the departure of the ice, the stream flow is reversed, forming *reversed streams.* Such is the upper Allegheny River, where oil wells sunk along this valley show the rock floor to be sloping northward while the present flow of the stream is southward.

## Marginal Glacial Lakes

It has been noted that when the ice margin was on plains and valleys sloping *away* from the ice, the water from the melting ice flowed away and often built outwash plains and valley trains. On the other hand, when the land surface sloped *toward* the ice the waters tended to accumulate between the ice front and the higher land in front, thus forming

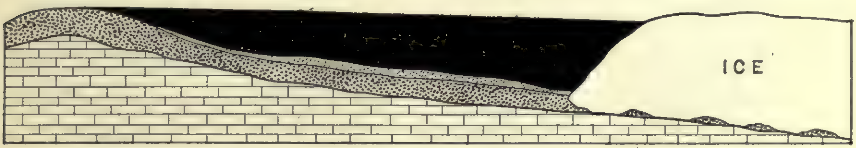


FIG. 208.—Section of a marginal glacial lake. The drainage has been blocked by ice to the right.

marginal glacial lakes. This is illustrated in Fig. 208, where the front of the glacier has melted back from a divide and a marginal lake has formed with the glacier acting as a dam to hold the water. The water accumulated until it rose to the lowest point in the land barrier, where it found an outlet, and often as the ice melted back lower outlets were uncovered so that many marginal lakes had several outlets. Finally, as the ice melted away, the lake was drained and became extinct.

Fig. 209 illustrates the changes in the extinct glacial Lake Maumee. In the upper diagram (*A*), the ice has melted back and a small lake has accumulated near the margin, draining to the southwest; the hilly belt (terminal moraine) marks a position of the ice margin when the glacier halted. In the diagram (*B*), the lake has enlarged and discharges to the northwest; a second terminal moraine marks a prolonged halt of the ice margin.

Many of the outlets of these lakes were of short duration, but some persisted for so long that they cut deep wide channels through solid rock. A case in point is the outlet of the former glacial Lake Chicago, the predecessor of the present Lake Michigan; the old outlet is a deep, wide valley through which a canal has been cut connecting Lake Michigan with the Illinois River.

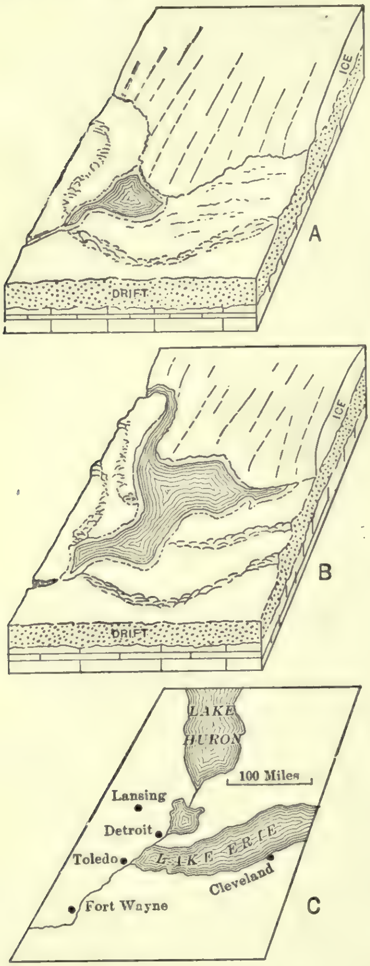


FIG. 209.—Diagrams showing stages in the glacial Lake Maumee. Present drainage in C. (Data after Leverett and Taylor, U. S. Geological Survey.)

Not only were marginal lakes formed during the ice retreat, but doubtless they were formed during the advance of the glacier. The traces of such lakes have, in most cases, been obliterated by the ice which advanced over their sites, but their existence has been inferred in some places by the presence of evident lake materials in moraines. These old lake sediments also add to the complexity of the drift.

**Features of Abandoned Glacial Lakes.**—Several features characterize these abandoned lakes. Shore lines, such as beaches, beach ridges, bars and deltas are in places so prominent and well preserved as to be evident to almost any one. Often there are two or more shore lines, one above the other, due to fluctuating levels of the water. The old outlets are often obscure to the untrained observer but many are easily recognized as the work of streams that have vanished. Often, during an ice halt, a terminal moraine was built in the lake and sometimes partly covered with lake sediments. The lake bottoms in the deeper portions are almost invariably very level plains unless they have been eroded since the glacial period, Fig. 232.

**Soils.**—Like all lakes, these marginal glacial lakes acted as huge settling tanks for the sediments carried to them by the streams, the sand, gravel and coarser materials being deposited near shore where streams enter and the finer materials were carried into deeper water farther from shore. However, there is an important distinction between these glacial lakes and other lakes; the debris from the melting ice front is added to the stream-carried sediments so that marginal lake soils may contain much till material. Another contrast is that, whereas many lake sediments are composed of well-weathered materials, the sediments of marginal glacial lakes contain much fresh material ground up by the glaciers and this is one cause of the usual fertility of these soils. Again many soils from lakes of this class show much less leaching and oxidation than soils of similar materials surrounding the lakes, a feature obviously due in large measure to the protective covering of the former lake waters.

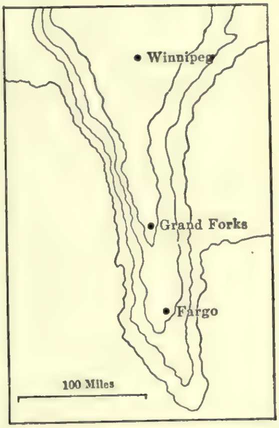

Fig. 210.—Some of the shore lines of Lake Agassiz. (After Upham, U. S. Geological Survey.)

Another very common characteristic of marginal glacial lakes is their more or less complex shore lines. As the glacier front advanced or retreated and closed or opened new outlets, the surface of the lake rose and fell and made new shore lines at each level provided the level was maintained for a considerable time. Fig. 210 shows the changes in level of an extinct lake. The outer line represents the lake at its highest stage. From this level the old lake surface with many pauses and readvances fell to lower levels. As a consequence of these changing shore lines, there is a belt of sandy soils near the margins of the lakes because the waves and currents here swept away the finer materials.

An illustration of this is seen in Fig. 211 which shows the soils and other features in a small area formerly covered by the extinct glacial Lake Agassiz. The waves and currents acting at different levels formed four distinct ridges in the western part of this area giving a belt of sandy soils about 10 miles wide. The sandy soils are due entirely to the sorting by the water and not to the till and lake sediments on which the waves worked. East of the sandy belt is the level lake bottom on which are heavy clay loams. Such extinct glacial lakes varied in size from a few square miles to hundreds of square miles in extent. They are of especial agricultural interest because of the large areas of exposed lake bottoms which, on the whole, yield very productive soils and their importance warrants further consideration of some typical examples.

The glacial Lake Agassiz is a relatively simple type, Fig. 212. At its maximum extent it was about 700 miles long, 250 miles wide and

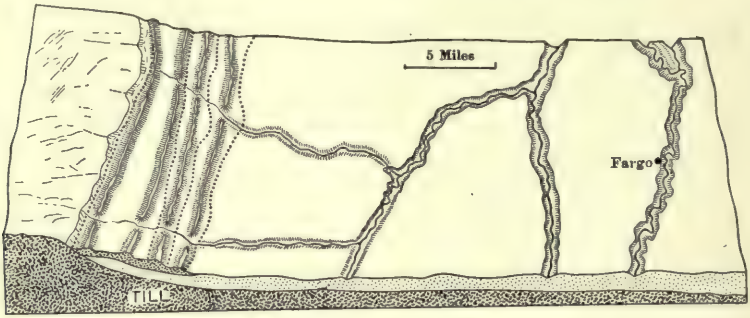


FIG. 211.—Part of the lake bed and shores of the former Lake Agassiz in North Dakota. The dotted lines indicate the distinct soils of the shore lines.

covered an area of about 110,000 square miles, an area about twice as large as New England or considerably larger than the present Great Lakes. As the ice front melted northward over the watershed between the Minnesota River and the Red River of the North, the water accumulated and for a long time flowed into the Minnesota River. Later an outlet farther north was uncovered, finally the ice disappeared and the present drainage into Hudson Bay was established. The old lake bottom is now a very level lake plain except where recessional moraines were built in the lake, and even these for the most part lose the rough knobs and hills of the land phase, and become belts of slightly undulating surface. Lake Winnipeg and many other lakes occupy depressions in the lake plain.

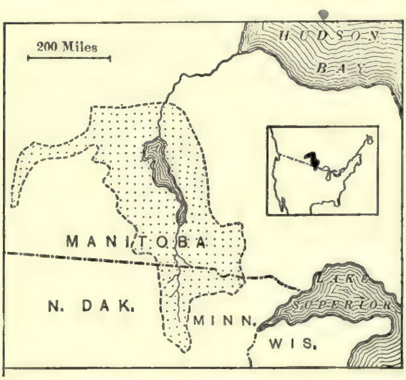


FIG. 212.—Map showing the greatest extent of the glacial Lake Agassiz. The present Lake Winnipeg occupies a small part of the extinct lake bottom. (After Upham, U. S. Geological Survey.)

The Great Lake region was occupied by a complex series of marginal glacial lakes of which the present lakes are the successors. Little is known of the preglacial topography of this region except that it was a lowland extending from New York to Wisconsin. The glaciers first advanced entirely over this region, later they retreated with many halts; they extended across the present St. Lawrence drainage lines, blocking the drainage and forming a series of lakes which outflowed to the southward. In addition there was some tilting of the land which, combined with the various ice advances and retreats, added to the complexity of these marginal lakes. Some of the different lake stages are shown in Fig. 213, which should be kept in mind as the description follows.

The glacial Lake Chicago occupied the Lake Michigan Basin and outflowed into the Illinois River; Lake Duluth occupied the western part of the Lake Superior Basin and found its outlet along the present St. Croix River; Lake Maumee occupied the western part of the Lake Erie Basin and outflowed into the Wabash River. Many later changes occurred, some of which are shown in the maps of Fig. 231. Lake Maumee, which occupied the western part of the Lake Erie Basin, may be taken as an example of these lakes, Fig. 209. At first a small lake was formed which flowed past Fort Wayne, Ind., into the Wabash River. As the ice retreated northward the lake increased in size and later the glacier receded and exposed a lower outlet through Michigan into the Lake Michigan Basin, when the water deserted the Fort Wayne outlet.

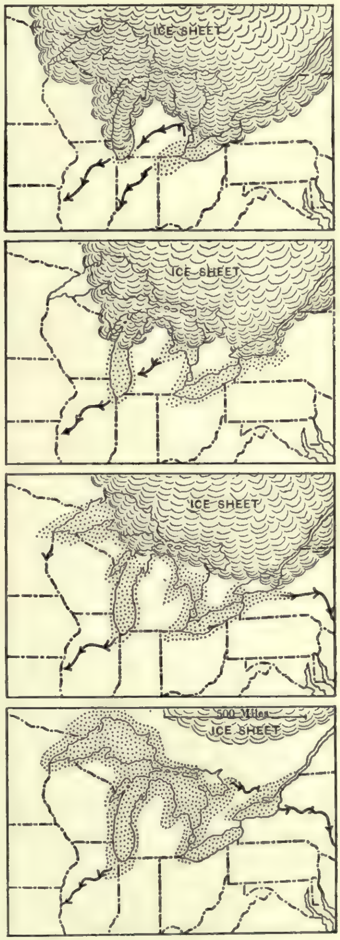


Fig. 213.—Different stages of the great glacial lakes (dotted areas). Outlets are shown by heavy lines, with arrows. (After Leverett and Taylor, U. S. Geological Survey.)

The upper maps show earlier stages. The question marks indicate that knowledge of the margin is at present incomplete.

The bed of Lake Maumee in northwestern Ohio is a level plain broken here and there by low, inconspicuous ridges of terminal moraines which were laid down in the lake. Old shores are generally marked by beach ridges which rise above the surface and the sandy soils of these ridges are often in sharp contrast with the heavy soils of the adjoining lake plain.

## STAGES IN THE GLACIAL PERIOD

**Introductory.**—We have assumed, for convenience of discussion, that the great continental glaciers advanced to their southern limit, then retreated and finally disappeared, but careful studies have shown that there were a series of glacial invasions (*stages*) each separated by intervals of no glaciation (*interglacial stages*). In proof of this, one traveling from St. Louis to Chicago will pass over at least three different drifts; the drift in southern Illinois is different in texture, composition and topography from that in the northern part of the state. A deep boring through the drift in northern Illinois and in many other places in the Middle West will often show a succession of drifts, buried soils and buried swamps as shown in Fig. 214. A study of this section shows that first the glacier deposited the lower till (Illinoian) and then retreated this till was exposed to weathering for a long time, a time so long that the upper portion of the till became leached and a thick layer of peat and soil was formed. After this the winds blew a layer of dust (loess) over the surface. Then the glacier again advanced, burying these

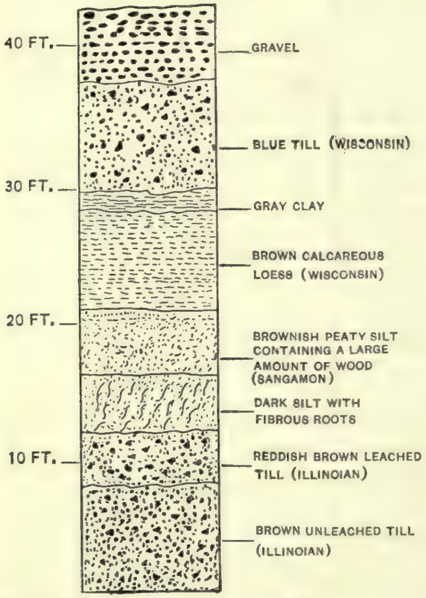


FIG. 214—A section of drift in Illinois showing the Wisconsin and Illinoian drifts separated by soils of the Sangamon interglacial period. (After Leverett, U. S. Geological Survey.)

materials beneath a deep layer of later (Wisconsin) drift. These and many other observations show that the glacial period was not a simple advance and recession of the ice, but rather a succession of advances alternating with extensive recessions during which the evidences point to a relatively mild climate.

In many cases the advancing ice eroded the drift of the preceding stage, but we have seen that glaciers often ride over loose debris without greatly disturbing it so that in many places borings show two or more different drifts, one above the other and often separated by buried soils, Fig. 214. From the standpoint of soils the distribution of drifts is very important. It will be seen in Fig. 215 that in general the older ice advances and their drifts (Kansas and Illinoian) extend farther south so that from south to north there are successively younger drifts exposed. In other words, with one probable exception the older invasions extended farthest south and each succeeding advance extended to less and less distances southward. It is obvious that the older drifts influence soils only when they lie beyond the overlying younger drifts or when the latter have been eroded, especially in valleys where the older, underlying drifts may influence the soils of the valley bottom and sides. Furthermore, it must not be assumed that the old drifts extend continuously beneath the younger drifts. In fact, *all* the drifts have never been found in any one place overlying each other and in large areas underlying drifts are entirely lacking, especially where later ice erosion was vigorous.

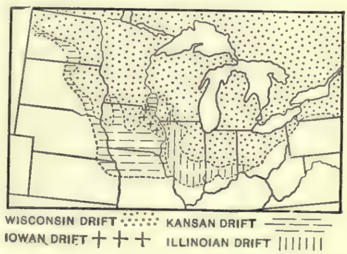

FIG. 215.—Map showing exposures of different glacial drifts. (After Leverett and Calvin.)

The succession of older drifts extending from beneath younger drifts is best shown in the upper Mississippi Basin and, in fact, this is the only locality in North America where there are large areas of older drifts. Studies have shown the presence of older drifts east of the Ohio but, for the most part, the exposures are scattering so that, from a standpoint of soils, the older drifts here are almost negligible.

**Soils and Glacial Stages.**—From an agricultural point of view, there are several important differences in these drifts. (1) Perhaps one of the most important contrasts is the greater degree of weathering to which the older drifts have been subjected. The older drifts have been oxidized to considerable depths with the result that the soils ordinarily have reddish or yellowish colors which, at variable depths, change to the ordinary bluish or grayish colors of the till. (2) The boulders and rocks of the older till are naturally more weathered; often the granitic rocks in old till are so weathered that they can be crumpled by the fingers. (3) Older exposed drifts are much more leached and their soluble materials carried away.

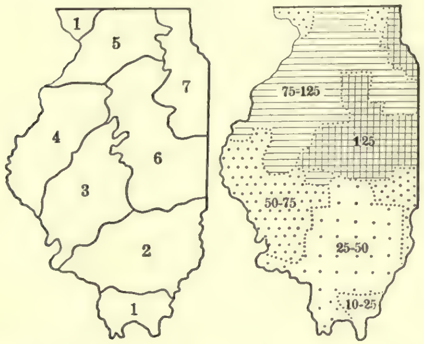

FIG. 216.—Map of Illinois showing different drifts as follows (after Leverett): (1) unglaciated; (2) lower Illinoian; (3) middle Illinoian; (4) upper Illinoian; (5) Iowan and pre-Illinoian; (6) early Wisconsin; (7) late Wisconsin. Map on the right shows average values per acre, 1909. (U. S. Census.)

The soils of Illinois, which are mostly glacial, furnish an interesting illustration of leaching in different drifts which are shown in Fig. 216. The ice here retreated in a general northerly direction, exposing in succession several different drifts, the southernmost being oldest and most widely exposed. The average analyses of these different soils according to Hopkins and Petit are as follows:[1]

AVERAGE NUMBER OF POUNDS PER ACRE IN SURFACE SOIL (0–7 INCHES) AND IN LOWER SUBSOIL (20–40 INCHES).

| Drift. | Soil. | | Subsoil. | |
|---|---|---|---|---|
| | Total phosphorus. | Total potash. | Total phosphorus. | Total potash. |
| Early Wisconsin, No. 7 | 1,360 | 34,700 | 2,970 | 110,200 |
| Late Wisconsin, No. 6 | 1,360 | 43,230 | 2,980 | 147,410 |
| Upper Illinoian, No. 4 | 1,240 | 32,490 | 3,230 | 98,580 |
| Middle Illinoian, No. 3 | 1,140 | 32,520 | 2,840 | 94,640 |
| Lower Illinoian, No. 2 | 900 | 28,390 | 2,780 | 91,980 |

It is evident that, in general, the older drifts contain less phosphorus and potash than the younger drifts and this difference is doubtless due in large measure to the longer weathering and leaching of the older exposed drifts. The composition is

[1] Bulletin No. 123, Illinois Agricultural Experiment Station, 1908.

not entirely consistent with the age of the drifts, but this is to be expected, since some of the drifts come from different sources and, moreover, all drift is variable.

(4) Finally the younger drifts are, as a rule, less eroded than the older, Fig. 217. It has been repeatedly noted that the humus content of a soil is to a considerable extent dependent on the drainage and the drainage in turn is closely related to the topography; as a result, the soils on newer drift ordinarily contain more humus. Some soils of the very latest drift are so recent there is comparatively little difference between soil and subsoil because there has not been time for the soil water to carry down the finer silts and clays into the subsoil. It must be remembered that many of the older drifts are covered with loess, which constitutes the soil material and so lessens the influence of the underlying drifts.

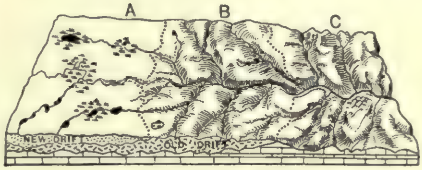


Fig. 217.—Diagram to illustrate the topography and drainage on new drift ($A$), old drift ($B$), and an unglaciated area ($C$).

Other features of less agricultural interest but of much scientific interest are (1) buried soils, peat bogs, lake beds and land fossils sometimes found between drifts; (2) interglacial valleys which were cut between ice advances, buried by later invasions and occasionally disclosed by stream cutting or well borings and (3) there are naturally found differences in rocks and till and in size of materials. In some cases no single one of the foregoing criteria would prove the existence of different drifts, but the association of several criteria is convincing.

**Stages in the Glacial Period.**—Six stages and five interglacial stages in the Mississippi Basin have been recognized as follows:[1]

*Late Wisconsin Stage.*
*Early Wisconsin Stage.*
*Peorian Interglacial Stage.*
*Iowan Stage.*
*Sangamon Interglacial Stage.*
*Illinoian Stage.*
*Yarmouth Interglacial Stage.*
*Kansan Stage.*
*Aftonian Interglacial Stage.*
*Sub-aftonian Stage.*

[1] Abridged from Chamberlin and Salisbury, Geology, Vol. 3, 1904.

**The Sub-aftonian stage** is typically found in Iowa, where it underlies younger drift and is not much exposed except in valleys. The till, as would be expected, is well weathered and contains a high percentage of igneous rocks; it also contains some sand and gravel which are sources of water supply for wells.

**The Aftonian Interglacial Stage** is marked by long weathering; it contains much gravel and sand and is also characterized by buried peat and trees.

**The Kansan Stage** is represented by widespread drift, Fig. 215, covering extensive areas in Kansas, Missouri, Iowa and Nebraska.

FIG. 218.—Topography on Kansan drift in Iowa. (Iowa Geological Survey.)

The till has a high clay content and, except locally, a low content of boulders. This drift is noteworthy for its very low content of water-laid materials; stratified gravel and sand are rather rare in this drift as a whole. Their absence, which indicates but slight water from melting ice, has not yet been adequately explained. Perhaps the ice disappeared by evaporation more than by melting. Moraines, kames, eskers and other features common in later drift are almost if not quite absent. The soils from this drift are somewhat heavy as a rule and silt loams are common types.

The **Yarmouth Interglacial Stage** was of considerable duration, as is shown by the deeply eroded exposed Kansan drift and by its weathered condition. This was followed by the **Illinoian Stage,** which has its greatest exposure in Illinois and adjacent states, Fig. 215. The till is high in clay and usually not stony. The upper portions are leached of their soluble lime carbonate for a short distance below the surface and are of yellowish-brown colors which grade into gray or bluish-gray below. Like the Kansan drift, there is little outwash or sorted material, although there is more than in the Kansan drift. There are comparatively few moraines, eskers and kames as compared with later drifts. The original surface was somewhat level although it is now considerably eroded in places, but the erosion has naturally not been so great as in the Kansan stage. Widespread loess deposits cover much of this drift so that the direct influence of Illinoian drift on soils is not so great as in many other drifts. The Illinoian stage was followed by the **Sangamon Interglacial Stage,** which was of shorter duration than the Yarmouth stage.

FIG. 219.—Iowan topography in Iowa. (Iowa Geological Survey.

**The Iowan Stage,** which followed, has the smallest surface exposure of any of the later drifts. Recent studies seem to show that this drift should be included with the Illinoian drift, but the question is not yet settled. This drift is thinner, is somewhat more sandy and contains more boulders than the preceding drifts; like them it contains but little water deposited material. Closely associated with this drift are widespread deposits of loess which form most of the soils. The **Peorian Interglacial Stage** separates this stage from the next following stage.

The **Early Wisconsin** and **Late Wisconsin** stages were separated by a short interglacial period. The Wisconsin drift is of especial soil interest because, while not extending far southward, this drift is of wider exposure since it was not covered by later drifts and, furthermore, the Wisconsin drift is not much covered with loess as compared with earlier drifts so that the soils are for the part derived directly from the drift. This drift is probably the most studied and best understood of any of the various drifts, in part because it is the most recent and, therefore, best shows the various glacial features. Much of the glaciation in the western mountains of North America was accomplished during the Wisconsin stages, and it was during these stages that the great marginal glacial lakes which have been noted were formed.

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## THE LOESS AND GLACIATION

The loess has been considered in some detail under a different heading but it should here be noted that, both in North America and Europe, important areas of loess are associated with glacial drift, although not all areas of loess are so associated and some drifts are not associated with loess. It is believed that the freshly exposed drift furnished much of the fine dust which now constitutes loess, especially in North America and Europe. In North America the largest loess areas overlie much of the Kansas, Illinoian and Iowan drifts and even some of the early Wisconsin areas and, moreover, the loess not only overlies these drifts but it extends in many places far beyond the drift borders. It is scarcely necessary to restate the fact that loess makes a productive soil; in many places, it is thick enough to form both soil and subsoil and in other places it forms the soil while the underlying materials constitute the subsoils.

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## VALUE OF GLACIATION

It is an interesting though complex question as to whether glaciation increased or decreased the soil values in glaciated districts. Unquestionably the average per capita wealth, the variety and extent of manufactures, the commercial development and in many places the average per acre value of agricultural lands are greater in the glaciated districts both of North America and Europe, but it would be unsafe to attribute these facts solely to glaciation. Soil values themselves are affected by commercial, economic and sociological factors as well as by topography drainage, texture, composition and climate.

On the whole, glaciation has produced good soils. They are less leached and the supply of available mineral plant food is greater than in most residual soils, but there are many exceptions in the case of sandy and gravelly fluvio-glacial deposits. The general effect of glaciation, especially of the continental type, is to reduce slopes both by scouring off projecting elevations and especially by filling depressions. Gentler slopes make for less erosion and thicker soils. Furthermore, the flat or gently rolling surfaces of ground moraines and some outwash plains favor the accumulation of humus, an important element of soil fertility. The soils of marginal glacial lakes are very productive and many very productive loessial soils are more or less derived from glaciation. On the other hand the extensive level surfaces due to glaciation are often swampy and glacial lakes occupy large areas of otherwise available lands. Both of these conditions result in much waste land and necessitate extensive use of ditch and tile drainage.

A fair comparison of the effect of glaciation on land values can be made only when glaciated and unglaciated lands are adjacent and as far as possible alike in other respects. After careful study of soil and crop values in the glaciated and unglaciated areas of Wisconsin, Whitbeck estimates that the increased valuation of glaciation to agriculture amounts to about $30,000,000 annually in spite of the fact that much of the driftless area is covered with fertile loess.[1] He summarizes in part as follows: "Notwithstanding the swamps and lakes in the glaciated area, 61 per cent is improved farm land against 43.5 per cent in the driftless area. In the fifteen driftless counties, the average value of farm lands and farm buildings is about $12,000,000 per county, against $18,000,000 in the glaciated area, a difference in favor of the latter of 50 per cent. In the driftless area, there are on the average over 126,000 acres per county of woodland and woodland pasture against about 50,000 acres in the glaciated area, the difference being largely due to the more rugged topography of much of the driftless area." The same general trend of values is brought out by Coffey's land value map of Ohio, Fig. 220.[2] The soils of Illinois, Fig. 216, also show not only higher

[1] Op. cit.

[2] Reconnoissance Soil Survey of Ohio, George N. Coffey, U. S. Bureau of Soils, 1912.

values of glaciated soils but also that, in general, soils of newer drifts are more valuable than those of older drifts. However, the comparison must not be carried too far, for we do not know the preglacial soils. On the other hand, the soils of New England have probably lost in productiveness through glaciation. The glaciers swept away the preglacial soils of New England and, in the main, deposited stony and sandy materials and these are thin in many places. It is very suggestive to note that much the same rocks and topography in regions of New Jersey, Pennsylvania and Virginia have productive soils and it is probable that the preglacial soils of New England were equally productive.

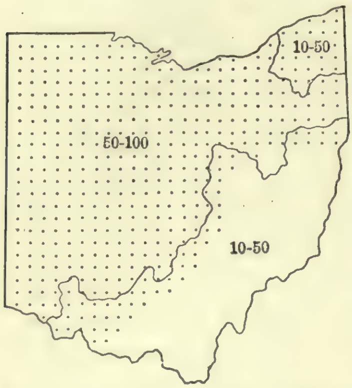


FIG. 220.—Map of Ohio showing land values in dollars per acre in 1909. The dotted area is glaciated. (After Coffey, Ohio Experiment Station.)

## CAUSES OF THE GLACIAL PERIOD

The causes of glacial periods are, of course, climatic, and the study of living glaciers or of the deposits of extinct glaciers gives but little clue to the causes of the last glacial period. The last widespread glaciation, known as the Glacial Period, is not the only one in the earth's history, for there are indisputable evidences of at least three former periods, one of which, the Permian (see page 296) was widespread. The various explanations so far offered have failed of general acceptance.

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## CHAPTER XI

## LAKES AND SWAMPS; LACUSTRINE AND CUMULOSE SOILS; LAKES; LACUSTRINE SOILS

**Introductory.**—Lakes and swamps are often closely associated and grade into each other so that it is appropriate to consider them together. A shallow lake is frequently termed a swamp during dry weather when the water is low. Many lakes are partly enclosed by swamps, and finally, as will be seen later, the ultimate stage of a lake is a swamp condition which later usually changes to arable land. Lakes and swamps are of great agricultural interest since lake beds and former swamps now constitute large areas of land and, furthermore, the reclamation of swamps is an important present and future problem.

### Kinds of Lakes

Lakes are bodies of water more or less enclosed by land; they lie in depressions or *basins* which are usually somewhat shallow although a few lakes are very deep. It is convenient to classify lakes according to the origin of their depressions and this involves a brief review of processes that have been discussed in preceding pages.

**Glacial Lakes.**—By far the most important process in producing lakes is glaciation. Indeed so characteristic are lakes of many glaciated regions that such regions can often be mapped by the abundance of small irregularly shaped lakes. Small *rock basin lakes* occupy depressions that have been excavated by glaciers; they are especially characteristic of mountain glaciation and have little agricultural interest. *Morainic lakes* by the thousands occupy undrained depressions in moraines. On terminal moraines they are usually small, roundish in outline and often without inlets or outlets, Fig. 221; many are the well-known "kettle lakes." Lakes on the ground moraine are usually larger. They occupy shallow depressions and are typically "strung along" a stream in a series of lakes and swamps. Finally there are many glacial lakes and ponds which do not fall strictly under any of the preceding classes but they, like all glacial lakes, are due to a deranged, immature drainage. The soils of the former marginal glacial lakes, which formed in front of the ice and drained away as the ice melted back, are especially important. A few of these lakes, like Lake Agassiz, were large, but there were many hundreds of smaller ones. The aggregate area of these old lake beds included millions of acres and their level surfaces and productive soils make them very important agricultural areas, Fig. 222.

Fig. 221.—Morainic lake occupying a depression in a terminal moraine, Montana. (Parks, U. S. Geological Survey.)

**River lakes** are often numerous along streams that meander in a flood plain. There are the crescent-shaped or "ox-bow lakes," Fig. 130, and the irregular "sloughs" that occupy depressions in the flood plain. One may find all gradations in the filling of river lakes, ranging from navigable lakes, swamps and filled swamps whose former existence is often indicated by their characteristic soils, Fig. 131. **Delta lakes** are well shown in the Mississippi Delta, Fig. 145, the chief of which is Lake Pontchartrain, a broad lake seldom over 15 feet in depth. Delta lakes because of their shallowness offer a promising field for reclamation.

Fig. 222.—Principal areas of lake soils in the United States. (After U. S. Bureau of Soils.)

**Coastal Plain Lakes.**—Shallow lakes are likely to accumulate in the depressions of a gently rolling surface such as are found in many coastal plains, which are recently upraised sea bottoms and have not been much eroded. Many of these lakes have been converted into swamps locally called "pocosins," and still others have passed the swamp stage and have become arable land.

## Effects of Lakes

(1) Lakes equalize temperatures, moderating both the cold of the winter and the heat of the summer. The grape belt along the southern shore of Lake Erie and the peach belt along the eastern shore of Lake Michigan are cases in point; the cool winds from the water in the spring retard the blooming of plants until danger from frost is past and in the fall the warm winds delay the coming of frost. The sugar cane on the southern sides of some Louisiana lakes is greener than on the northern side because of the moderating effects of the lakes on northerly winds. (2) By acting as natural reservoirs, lakes regulate the flow of streams. A flood stream flowing into a lake finds a larger channel in which to expand and so the water is distributed. (3) In dry seasons the water from lakes escapes rather slowly and so preserves the flow of streams. The principle of artificial storage lakes is advocated by some as a means of flood control.

(4) Lakes act as great settling tanks. Inflowing streams, upon reaching the quiet waters of a lake, lose their velocity and their load of sediment is deposited. A classical example of this function of lakes is Lake Geneva. The Rhone enters the lake a turbid, muddy river and emerges as a stream of remarkable clarity. Again, the streams entering Lake Erie carry loads of sediment and some of them have built under-water deltas of considerable size. On the other hand, the Niagara River, which drains Lake Erie, is a clear river, so clear, indeed, that the underlying rock bottom can be seen as the river rushes over the American Falls.

## Shore Regions of Lakes

Waves and currents are commonly more often associated with oceans than with lakes, for ocean waves attain much the larger dimensions. Nevertheless, waves on lakes of even moderate size may attain considerable heights and accomplish notable work. Thus the old lake (Lake Bonneville) that formerly occupied a portion of the Great Basin cut cliffs and built shore lines which remain to-day as notable features long after the old lake has disappeared. Wave and shore current work of extinct lakes is of especial agricultural interest since many former lake shores are now occupied by arable soils.

### Waves

As a wave approaches a shelving shore, the lower part is retarded by friction on the bottom while the upper part continues at its former speed with the result that the wave " tips over " or " breaks," forming the breakers or *surf*, Fig. 244. The waters of the surf run back seaward beneath the incoming waves making an under-water current called the *undertow*, Fig. 223. It is at once evident that, when waves are running high, they are an extremely efficient agent of erosion in the surf and undertow, for the large waves break with a force of tons per square foot, loosening and breaking shore materials, some of which the undertow carries away.

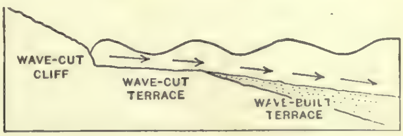


FIG. 223.—Diagram to illustrate wave and current work. The arrows show the direction of the undertow.

**The work** of these three agents, wave, surf and undertow, is thus both destructive and constructive, the former activity usually being the most conspicuous. When a wave breaks upon a shore, it loosens debris, some of which is removed by the undertow, but much is moved back and forth, thus rounding the materials and grinding them to smaller and smaller dimensions, Fig. 243. Thus it is that old shores are almost invariably sandy or gravelly. The undertow rapidly loses its velocity as it moves toward deeper water and it can carry only fine materials to any considerable distances; the coarse materials are left near shore. As a result, there are under some conditions the following features due to wave work: the surf beating upon the shore cuts a *cliff;* the rapid undertow near the shore, armed with gravel and sand, cuts a smooth somewhat sloping *wave-cut terrace*, and farther out the undertow constructs a *wave-built terrace*, Fig. 224. Owing to various complications these three forms are often lacking and are usually more or less merged into a sandy, gravelly, sloping beach. Sandy and gravelly soils mark the old shores of many extinct lakes, an example being given in Fig. 227, where the gravelly and sandy soils occur in three belts, each belt made at a different height of the former Lake Agassiz.

For the sake of simplicity the waves have been described as coming straight on shore, but very often they strike the shore obliquely as in Fig. 225. In such instances a portion of the wave energy is used to produce a shore current more or less parallel to the coast, a current which carries the sand and gravel along the coast and often builds bars across bays and inlets. Sandy Hook, which nearly encloses New York Harbor, is built by southerly shore currents; the deposits here brought by these currents require constant dredging to keep the harbor channel open.

FIG. 224.—Wave-cut terrace of an extinct glacial lake at the right; wave-cut cliff at the left. (Alden, U. S. Geological Survey.)

**Barrier Beaches or Off shore Bars.**—It has been noted that the undertow carries out debris which it often deposits. Furthermore, on shallow coasts the waves drag debris shoreward and often build up a low ridge. Because of these two agencies acting either singly or together, a low under-water ridge is often built up to the height of the storm waves. The winds catching up the sand build it into dunes and spread the sand so that a long, low ridge is formed, often termed a "sand reef" or "barrier beach." Such are common along the south Atlantic and Gulf coasts. The coast of Texas is practically fringed by such bars with only a few breaks or "inlets." Galveston is built on one of these bars, Fig. 245.

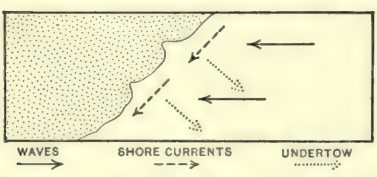


FIG. 225.—Diagram to illustrate the development of shore currents.

**Shore Lines at Different Water Levels.**—It has been assumed that the water surface holds about the same level while the waves are working and this is practically true for the sea level at least, for a long period, but, in the extinct lakes with which we are especially interested from an agricultural point of view, the lake surfaces suffered many variations of level. For example, nearly a dozen shore lines have been identified around the extinct Lake Agassiz, each recording a separate level of the lake. As these lakes were filling or draining the waters cut shores as they rose or fell, but no marked shore lines were made unless the water surface was maintained at practically the same level for a long time. The best-preserved shore features were naturally made when the lake waters were falling, since the waves of a rising lake would modify or destroy the previous bars, cliffs and other features.

**The soils associated with lake beaches** may be roughly divided into two classes, first those formed where the lake surface was at fairly constant level so that well-defined shore features were made; second those formed where the lake surface was shifting and the wave action was in consequence relatively ineffective in producing well-marked shore features. The typical arrangement of soils in the first case will be readily understood from the general principles of wave work. The breaking waves detach and loosen debris and roll it back and forth while the finer materials are carried out by the undertow. Then at places where conditions are favorable, the incoming waves build gravelly ridges which now stand as prominent features above the lake plain,

Fig. 226.—Beach ridge of an extinct glacial lake, Mich. (Leverett, U. S. Geological Survey.)

Fig. 226; such ridges are very prominent in northern Ohio where they are often utilized as main roads across the lake plains. Typically, the soils in such shore belts as we are considering show a roughly belted arrangement. (1) The belt of surf and swift waters are marked by coarse-textured soils such as gravels and gravelly loams. (2) On the other hand, the belt deposited by the undertow would show progressively finer materials as the distance from the old shore increases and the soils would be mainly loams and sandy loams while (3) in the deeper, quiet, waters, clays and clay loams would predominate.

Such an ideal arrangement is seldom to be found, but a large area of soils shown in Fig. 227 exhibits this arrangement. The soils due to the active waters of the surf

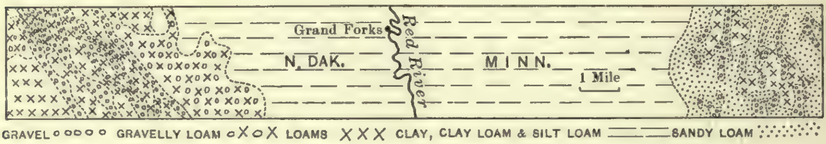


Fig. 227.—Shore and deep-water soils of the extinct glacial Lake Agassiz. (After U. S. Bureau of Soils.)

and shore waters are gravelly; this gravelly belt changes to the loams deposited by the undertow and lastly, clays, silts and silt loams were deposited in the deeper, more quiet waters of the lake.

A soil arrangement illustrating the second class in which the shore was shifting is illustrated in Fig. 228. It should, however, be remembered this area in places also includes soils made by water that was more or less at a constant level; in fact, the two classes of soils are very seldom entirely distinct for any considerable area. A broad belt of sandy soils (*LS*) was made by advancing and receding wave action with here and there gravelly and sandy ridges built by the waves when the water level was stationary for some time. This belt is coarse-textured because the finer materials were carried to deeper waters. Where the wave zone moved over areas of boulder clay, much of the finer materials were removed and the stones left, thus resulting in stony clays (*LCT*). On the other hand, where the materials were sandy (sandy till) the currents removed most of the clay, leaving sandy soils (*LST*). The larger area of lacustrine soils is found as usual where the waters were deep and quiet and the finer materials settled furnishing clays and clay loams (*LC*). *TC* and *TM* in the map represent upland soils, the former somewhat clayey and the latter somewhat sandy. It will be noted that the ridges are often discontinuous and that they branch frequently and not infrequently they change directions. Such ridges are usually most distinct where winds are strongest

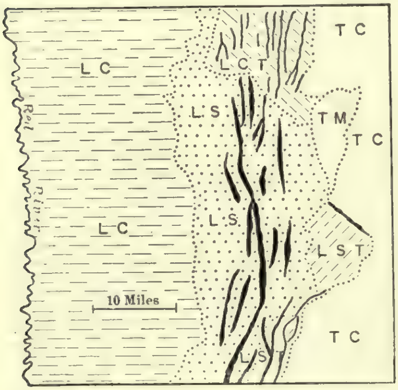


Fig. 228.—Lacustrine soils deposited in the former Lake Agassiz in northwestern Minnesota. The dark lines are beach ridges. (After Leverett, Minnesota Geological Survey.)

and most persistent for, under such conditions, wave action is most effective, other things being equal. Shore soils also show much variation according to the materials of the beach, wave strength, wind persistence and direction shore currents and, of course, the persistence of the lake level which necessarily determines how long the waves can work.

Fig. 229.—One of the series of level-topped deltas built one above the other at different lake levels, N. Y. The road runs at the foot of the delta. (O. D. von Engeln.)

**Deltas** are often conspicuous shore features of lakes especially since there are seldom waves and currents strong enough to interfere greatly with delta building; as a result even small streams have built considerable deltas. These deltas of extinct lakes often rise along valley sides in a series of level-topped deltas much like huge steps, Fig. 229, each step having been built at different levels of the water. Deltas and their soils have been considered in foregoing paragraphs and do not call for more extended notice here, except to call attention to the soils of a delta which was built in the extinct Lake Agassiz, Fig. 230, a delta which will serve as an example of many. The Sheyenne River, now a tributary of the Red River, was a much larger stream when it flowed into Lake Agassiz and built a delta that now covers some 800 square miles. The delta building occurred at one of the earlier levels of the lake and, with the falling of the lake waters, the river cut a channel through its delta. The soil particles show a progressive decrease in size from the head of the delta towards the delta margin, a decrease due to the diminishing velocity of the delta building stream.

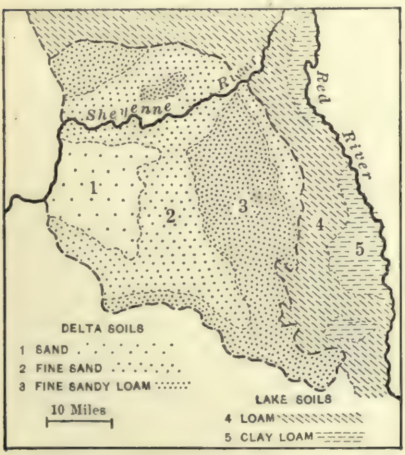


Fig. 230.—Soils of the old delta which the Sheyenne River built into the extinct Lake Agassiz. (After Upham, U. S. Geological Survey and U. S. Bureau of Soils.)

### Lake Deposits and Lake Basins

There is naturally a close relation between lake deposits and the materials forming their basins. Sandy basins will ordinarily yield sandy lake sediments and a basin of clay or calcareous materials will yield somewhat characteristic lake sediments. This is well-illustrated on a large scale in the soils now occupying the bed of the former glacial Lake Maumee in northwestern Ohio, Fig. 231. Most of the tributary upland is covered with calcareous soils derived from limestones and the lake soils, especially the old shore soils show fragments of limestone and the subsoils are usually alkaline. In the northeastern part of the basin the upland soils are largely from shales and sandstones and in consequence the shore soils and the corresponding lake sediments are much more sandy.

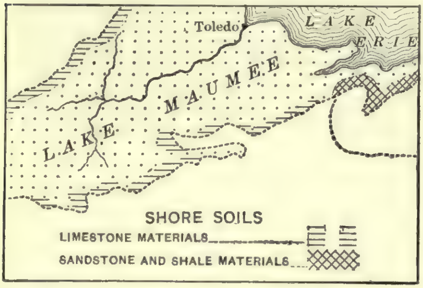


FIG. 231.—Shore soils around a portion of the extinct glacial Lake Maumee. Limestone materials yield calcareous soils and sandstone and shale materials, sandy soils. (After Ohio State Soil Survey.)

It is important to note that the shore soils of lakes show a much closer relation to the materials of the basin than the soils derived from deep-water sediments. The finer silts and clays, which are deposited in deep waters, are common to many soils derived from greatly differing rocks and the origin of these sediments either in rivers or lakes is usually difficult to trace. Probably the most characteristic of these finer sediments are those of calcareous origin and soils from such sediments often show a high lime content. Shore materials from granite, shale, sandstone and other rocks are usually easily identified by the pebbles. Weak rocks, like shales and some sandstones, ordinarily furnish finer shore materials than strong rocks such as granites. Furthermore, shore materials from such igneous rocks as granite usually furnish soils with higher contents of lime and potash than those from shales and sandstones and the shore soils built of limestone materials are usually more or less calcareous. The materials in the basins of small lakes are far more likely notably to influence the lake sediments than in large lakes, since large lakes usually receive a greater variety of sediments and there is more mixing of sediments. Delta and river lakes usually yield fine-grained soils because the streams, as a rule, are carrying finer materials in their lower courses where these lakes are found.

## Extinction of Lakes

It has been noted that lakes are relatively short-lived geological features. They become extinct in two ways, by *draining* and by *filling.* As the outlet of a lake is lowered by cutting the outlet channel, the water is drained from the basin and the surface is lowered. On the other hand, lakes are filled (1) by inwash from the sides, (2) by deposits by inlets and (3) many lakes are more or less filled by accumulations of vegetable matter in them. Obviously these three agencies of extinction may and often do operate simultaneously. Since there is no sharp distinction between lakes and swamps and, moreover, since lakes tend to become swamps in later stages of their filling, the discussion of this topic will be taken up in detail under the topic of swamps. It is sufficient to note here that there are thousands of small lakes which have been filled or drained and have become arable land and, as population becomes more dense, many lakes and swamps will be reclaimed and their soils utilized.

## Topography of Lake Bottoms

The most notable topographic feature of exposed lake bottoms is their level surface, forming *lake plains* which are due to the slow, even

Fig. 232—The plain of Lake Agassiz, North Dakota. The distant trees mark the course of the Sheyenne River. (W. C. Palmer, North Dakota Agricultural College.)

accumulation of fine materials which settle to the bottoms of the lakes. In time, if the lake exists long enough, any original inequalities of the bottom become buried, but not infrequently some higher hills are not covered and now rise through the lake sediments above the surrounding plain. The surface of Lake Agassiz plain, Figs. 212 and 232, is so level that, owing to the earth's curvature, the tops of elevators and other buildings are first seen as they are approached, an effect often observed at sea. Beaches, of course, do not have the level topography of the plain formed in deeper waters.

### Lacustrine or Lake-made Soils

are usually productive. The most extensive connecting areas of these soils are the exposed bottoms of the extinct marginal glacial lakes, because these lakes have entirely disappeared while most other glacial lakes have not yet been filled or drained. Filled river lakes are not uncommon and some soils of partly filled coastal plain lakes have been utilized.

The level topography of lake plains produces three important agricultural factors: (1) The drainage problem both surface and subsurface is important. (2) The level surface and practical absence of stones allows the fullest use of agricultural machinery. (3) Another somewhat characteristic feature of many lacustrine soils, especially in humid climates, is their high humus content due to their slow drainage.

Lacustrine soils as a whole are fine-textures, mostly silts and clays, because the largest areas were deposited in quiet waters. The shore regions are more sandy. Beach soils vary from gravels to loams according to the materials with which the waves worked, to the strength of the waves and shore currents and to the length of time during which these agents operated. There is a tendency for lacustrine soils to have a roughly concentric arrangement, ranging from the fine-textured soils of the deep waters to the coarser-textured soils of the beach and shallow-water areas, but the arrangement is often very irregular. Many river and delta lakes are exceptions to the above statements for they are in part filled by overflows from the rivers and such river sediments are usually fine so that these soils are typically clays, clay loams and silt loams. In general, the soils of small extinct lakes are less variable than those of larger lakes, since their deposits are more closely associated with the lake basins and, furthermore, there is usually less distinction between shore and deeper water deposits, because wave action on small lakes is usually weak.

### Saline Lakes

These are found in regions of deficient rainfall when lakes have no outlets. The salt (NaCl) and other soluble materials, which are carried into the lakes, are left behind when the waters are evaporated and as this process goes on, the salts keep accumulating until the waters become saturated for some substances and deposition begins. This process has agricultural interest for, as will be seen later, some potash fertilizers are believed to have accumulated under similar conditions.

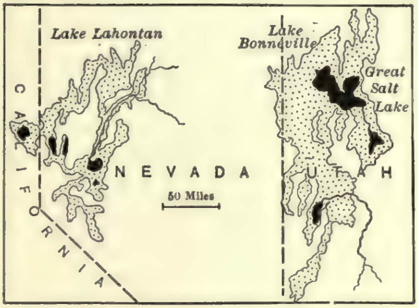


FIG. 233.—Areas formerly covered by the extinct Lakes Bonneville and Lahontan in the Great Basin. Great Salt Lake is a remnant of Lake Bonneville.

The Great Salt Lake, Fig. 233, is of interest in this connection. Not long ago, geologically speaking, there were several fresh water lakes in the Great Basin of which Lake Bonneville was the predecessor of the present Great Salt Lake. The waters of this fresh-water lake flowed northward into the Snake River, cutting a deep valley, and the waves formed hundreds of miles of shore forms which are now almost as

FIG. 234.—View across an arm of the extinct Lake Bonneville, Utah. (U. S. Bureau of Soils.)

perfect as when they were built, their preservation being due both to their recency and to the scanty rainfall of the region. The study of these shore lines, now so well exposed and easily examined, has thrown much light on our knowledge of shore forms. As the rainfall of the region diminished, Lake Bonneville began to shrink and when the waters fell below the surface of the outlet, the waters became increasingly salty until the present Great Salt Lake remains a remnant of the much larger fresh Lake Bonneville.

## SWAMPS, CUMULOSE SOILS

Swamps occur when land is covered with shallow water for all or a considerable part of the year or when the soil is kept wet much of the time so that vegetation in falling does not completely decay. Swamps are interesting from an agricultural point of view (1) because many soils are derived from swamp deposits; such soils are called *cumulose soils*. (2) Many prairie soils have been subjected to semi-swamp conditions so that they are well supplied with humus. (3) Again, the problem of swamp and marsh reclamation is extremely important in many regions. (4) Finally, swamps are of further interest in that beds of peat and coal were formed under swamp and marsh conditions and a study of present swamps helps in understanding these past conditions.

### Factors

Some conditions affecting the formation of swamps are as follows: (1) Topography; flat land from which the run-off is slow and areas depressed below surrounding areas so that drainage is toward the swampy areas are both favorable to swamp conditions. (2) Rainfall and evaporation are obviously important factors; in an arid region, swamps are infrequent although some occur and are supplied with water apart from local rainfall. Rapid evaporation evidently militates against swamps. (3) The amount and nature of vegetation is important because vegetation tends to retain moisture and so promote swampy conditions. Indeed, under some conditions an abundant growth of vegetation may in itself bring on swampy conditions. (4) The porosity of the subsoil or underlying formations obviously affects the downward movement of waters; most large swampy areas are underlain by relatively impervious clays or silts which retard the downward escape of water.

## Classes of Swamps

The classes of swamps correspond closely to those of lakes because lakes and swamps grade into each other. A common usage is to restrict the term *swamp* to those of fresh-water origin while similar features of salt water origin are often termed *marshes.* Although there is often a close connection between lakes and swamps, it does not necessarily follow that all swamps were preceded by lakes or ponds, although many swamps have had these predecessors. Swampy or semi-swampy conditions may result from poor drainage, an increase in rainfall or by an increased growth of some types of vegetation which retain moisture and lead to swampy conditions, an illustration being the so-called climbing bog, which by rank growth of vegetation may spread beyond the original borders and so extend a swamp area.

*Glacial swamps*, like the glacial lakes, are most numerous. The glaciers left many shallow, undrained depressions and a drainage so disorganized that these depressions in most instances are as yet undrained and remain as lakes and swamps. Most morainic lakes are shallow, many have been completely filled since the Glacial Period, while thousands of others are yet in various swamp stages, Fig. 235. Large swamps are found on many ground moraines where water stands in broad, shallow depressions, some of which are completely filled and are covered with deep, black soil, Fig. 236.

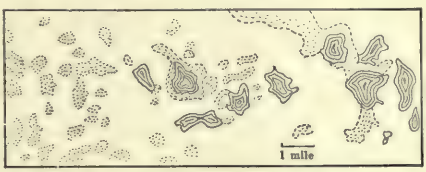


FIG. 235.—Glacial lakes and ponds wholly or partly filled, North Dakota; dotted areas indicate lacustrine soils. (U. S. Bureau of Soils.)

*Alluvial swamps* are of great present and potential importance especially along the larger rivers where they have formed on the back lands some distance away from the streams. The alluvial swamps along the lower Mississippi extend for long distances with but little interruption. Alluvial swamps may be roughly divided into two classes. (1) The oxbow lakes along rivers have been noted, page 158; these in time reach the swamp condition and later become filled. (2) The larger and more important swamps are found in the low back lands where drainage is sluggish. It is these river swamps which offer fairly easy reclamation and, when reclaimed, they furnish very productive soils. These swamps now are for the most part wooded and the vegetation helps to fill them by catching the sediments brought by the waters.

FIG. 236.—Onions on muck soil. A filled glacial swamp, N. Y. (U. S. Bureau of Soils.)

*Coastal Plain Swamps.*—Swamps and swampy areas are common on the level areas of the Coastal Plain, especially in the "flatwoods" and prairies of this region in Virginia and the Carolinas. These areas have the "appearance of a dead-level plain varied occasionally by slight hollows and ridges and by shallow valleys" (Bennett). In some places the slopes are so gentle that the ground water is at or near the surface and swampy conditions result; in other places swamps, often locally called "pocosins" form in slightly depressed areas. The Great Dismal Swamp of Virginia and South Carolina, Fig. 237, is an example of a coastal plain swamp. The swamp has formed in a slight depression and near the center is Lake Drummond, which is apparently a portion of a lake once larger, but which has been filled by encroaching


FIG. 237.—Map of Dismal Swamp, Va.

vegetation. In many places on the flat Coastal Plain, only the occurrence of peaty or humus areas shows the former existence of a swamp.

**Filling of Lakes and Swamps**

There is little essential difference in the filling of lakes and swamps. Both are subject to some filling by inwash, although this process is usually more prominent in lakes than in swamps. On the other hand, the work of vegetation in filling is on the whole more important in swamps than in lakes, mainly because swamps are generally shallow so that dense vegetation, rooted in the bottom, thrives better in swamps.

FIG. 238.—Vegetation filling a lake. The old shore line was formerly at the hill on the left. (Fenneman, Wis. Geological Survey.)

The filling of a lake and swamp is illustrated in Fig. 239. In the zone of shallow water about the shores, aquatic rooted plants such as reeds, canes, grasses and some shrubs will begin to grow. The leaves, twigs and stems of these plants fall into the water, partially decay, sink to the bottom and shallow the water until rooted trees can get a foothold. The process is repeated until the soil becomes dry enough for dry land trees and the marginal parts of the swamp or lake become essentially uplands. Roots and stems also arrest the sediment washed in and this is added to the soil that is forming.

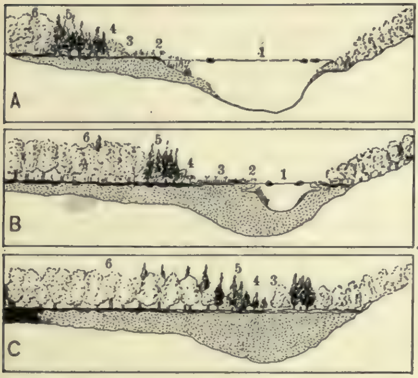


FIG. 239.—Diagram illustrating the filling of lakes by vegetation. (1) Open water and aquatic plants; (2) marginal and shore plants; (3) swamp meadow; (4) swamp shrubs; (5) swamp forest; (6) upland forest. (After Dachnowski, Ohio Geological Survey.)

Meanwhile, floating plants such as mosses which float on the surface and thread-like plants (algæ) which grow on the bottom are also filling the deeper parts of the lake or swamp. Floating mats of such plants and of shore plants are common features; these mats often attain considerable area and thickness and in time become waterlogged and sink to the bottom, thereby building up the bed of the swamp or lake. Fig. 239 shows three stages in lake filling by vegetation; on the right are steep sides and on the left are gently sloping sides. In the first figure (*A*), the vegetation has filled the shallow water and built up a peaty matting out to the deeper water. The zones of upland, swamp and of water vegetation encroach on the lake until in the last stage (*C*) the lake or swamp has been converted into land. Thus, many lakes and swamps in process of filling show several zones. The shore waters become shallow and finally form land which supports land vegetation. In front of this is a bog with trees, shrubs, grasses and reeds. Fronting this is a low, swampy shore and finally more or less open water with floating mats of vegetation and this in time becomes partly filled with vegetable matter and becomes a "quaking bog." Finally the entire area may become firm land and the zonal arrangement of vegetation disappears. All stages are found from lakes and swamps which have but narrow zones of encroaching vegetation to those which are entirely changed to arable land.

In the warmer climate of the South, mosses are not important agents in lake and swamp filling. Here the grasses, reeds, "cane" and dwarf palmettos, all rooted plants, form a dense growth in places, according to Shaler, of 50 to 75 plants to a square foot. The work of the mangrove trees is especially effective in some southern swamps, particularly in the Everglades of Florida. The branches of this tree bend down and take root in the swamp bottom so that there is a zone of vegetation advancing on the water. The dense growth catches sediment, the falling leaves and twigs are added to the sediment and the swamp fills up from the shores. The Everglades of Florida is a good example of these swamps, Fig. 240. They "owe their existence primarily to an abundant rainfall and to the slight elevation of southern Florida. Even were there no basin-like structure whatever, and were the bed rock absolutely flat, the present rainfall, the sluggish drainage and the luxuriant growth of vegetation would result in a swamp"


FIG. 240.—The Everglades of Florida. Lake Okechobee lies within the Everglades. (After Sellards.)

(Sellards). A section of a portion of the Everglades is shown in Fig. 241.

### Lake and Swamp Deposits

**Bog Lime (Marl).**—Bog lime is a deposit of calcareous materials in lakes, bogs or swamps; it is often incorrectly termed marl. Strictly speaking, marl is a calcareous clay which varies considerably in composition. Marl beds are not infrequently found in lakes and swamps, the marl being in some cases highly calcareous. To some extent marl and bog lime are caused by the accumulation of shells, especially minute shells, as they sink to the bottom. However, it is believed that most of these materials are secreted from the water by plants, particularly by certain thread-like plants (algæ) which deposit lime in their tissues and on their surfaces. Both materials often have a composition suitable for cement and are used for this to some extent for that purpose. They also yield lime and are commonly used locally for fertilizers, especially when they contain considerable lime phosphate, as is often the case.


FIG. 241.—Section of a part of the Everglades which here occupies a shallow limestone basin. (After Sellards.)

**Peat** is formed from the accumulation of partially decayed plants and occurs in all stages from plant stems, roots and twigs but little changed to a much changed black, waxy substance. It is found in many swamps and lakes, especially in cool climates. It is due to incomplete decay as vegetation falls into water and then by the aid of bacteria is changed into peaty substance. Peat is used agriculturally as an absorbent and has some local use as a fertilizer, especially for sandy soils. In Europe peat is used to a considerable extent as fuel. Peat is of further interest in that it represents one of the early stages in the formation of coal. Swamps are now an important source of timber. Owing to the difficulty of removal, swamp timber has until recently been practically uncut, but this source is now perhaps our greatest timber reserve.

A common manner of swamp and lake filling, together with the accumulation of peat and marl, is shown in Fig. 242. In the first stage ($A$) there is a growth of plants which slowly fill the marginal waters. In the deeper waters the small thread-like plants secrete more or less lime which accumulates on the bottom as marl as the plants die. Meanwhile, the shore vegetation is causing a deposit of peat which accumulates above the marl so that there is an advancing zone of marl followed by an overlying following zone of peat (*B*). A later stage is shown in (*C*) which is a common occurrence. It is evident that, other things being equal, marl will accumulate more rapidly where the surrounding materials are calcareous, a condition often found in glacial materials where calcareous rocks have been ground up and are therefore readily leached by the ground water.

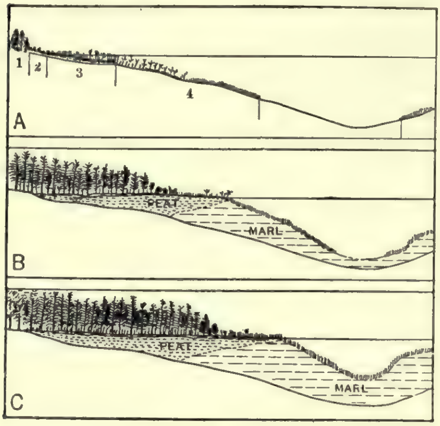


Fig. 242.—Diagram to illustrate the accumulation of peat and marl in a filling lake or swamp. *A* represents an early stage with the following plant zones: (1) conifers; (2) bog shrub; (3) bog hedge; (4) aquatic plants. (After Transeau.)

## Cumulose Soils

These soils, like lacustrine soils, are characterized by their high humus and nitrogen content; they vary from black, waxy soils to peaty soils and to loams and clay loams with high humus content. The high humus content is due, of course, to the large proportion of vegetation filling in swamps and, since this process is more prominent in swamps than in lakes, the cumulose soils usually show higher nitrogen than lacustrine soils.

These principles are well shown in the following table, which shows high nitrogen both in soil and subsoil of recent cumulose soils. It is interesting also to note that the nitrogen content is higher on the flat prairies than on the undulating prairies, a difference due mainly to the slower drainage and consequently greater accumulation of vegetable matter on the flat prairies.

The mineral content of cumulose soils varies considerably, but in general the potash is low as is shown by the table above. The phosphoric acid and lime is often rather high owing in large measure to the accumulations of lime, secreting plants and animals. The mineral content, of course, will vary with the character of the materials that are washed or blown into the swamps. Furthermore, where the contributing vegetation is rooted there is naturally more mineral matter from this source than from floating plants since rooted plants are in direct connection with the under-water soils.

TABLE SHOWING THE AVERAGE NUMBER OF POUNDS PER ACRE IN SOME ILLINOIS SOILS (0–7 INCHES) AND SUBSOILS (20–40 INCHES) OF NITROGEN, PHOSPHORUS AND POTASSIUM [1]

| Soil Area. | Soil Type. | Nitrogen. | | Phosphorus. | | Potassium. | |
|---|---|---|---|---|---|---|---|
| | | Soil. | Subsoil. | Soil. | Subsoil. | Soil. | Subsoil. |
| **Prairie Lands, *Undulating*** | | | | | | | |
| Middle Illinoian...... | Brown silt loam.. | 4,370 | 3,440 | 1,170 | 2,680 | 32,240 | 90,040 |
| Late Wisconsin....... | Brown silt loam.. | 6,750 | 3,630 | 1,410 | 2,630 | 45,020 | 160,140 |
| **Prairie Lands, *Flat.*** | | | | | | | |
| Middle Illinoian...... | Black clay loam.. | 5,410 | 3,020 | 1,430 | 3,030 | 31,860 | 94,900 |
| Late Wisconsin....... | Black clay loam.. | 8,900 | 3,180 | 1,870 | 3,090 | 37,370 | 125,370 |
| **Swamps and Bottom Lands** | | | | | | | |
| Old bottom lands..... | Deep gray silt loam......... | 3,620 | 2,280 | 1,420 | 2,620 | 36,360 | 101,610 |
| Late bottom lands.... | Brown loam..... | 4,720 | 4,150 | 1,620 | 2,410 | 39,970 | 119,520 |
| Late swamp......... | Deep peat...... | 34,880 | 97,730 | 1,960 | 3,740 | 2,930 | 11,510 |

[1] Hopkins and Pettitt, Bulletin No. 123, University of Illinois, Agricultural Experiment Station, 1911.

As a rule the proportion of organic matter in swamp soils increases from the margin toward the center. The marginal zone of soils catches more of the sands, silts and clays that are washed and blown into the swamp and in this zone is found the longest duration of rooted plants and trees. This variation is well shown in an analysis of soils from a coastal plain swamp in North Carolina as follows:[1]

| | Silica. | Alumina. | Organic Matter. | Water. |
|---|---|---|---|---|
| Marginal soil................ | 84.54% | 2.69% | 7.70% | 2.50% |
| Swamp center................ | 1.52% | .39% | 87.25% | 9.60% |

[1] Quoted by Merrill, op.cit. from Geology of North Carolina, Vol. 1, 1875.

River and delta swamps are somewhat subject to floods and their soils are, therefore, likely to show a higher content of sand, silt and clay, but they vary considerably, so that old river courses and swamps may be marked either by sandy loams or by muck and peaty soils, Fig. 131. Muck and peaty soils have proved especially adapted to onions, celery and other small truck crops. The celery district of Michigan includes large areas of cumulose soils on which the celery is grown for the most part. Many swamps in cool climates which can be inundated are used extensively for cranberries. Swamp reclamation in many respects is easier than lake reclamation but, except locally, but little has been done in North America. Shaler estimates that from 105,200 to 131,200 miles of swamps and shallow lakes in the United States can be fairly easily reclaimed. As an indication of the possibilities of these lands, the same author estimates that "probably not far from one-twentieth of the tilled lands in Europe were inundated and unfit for use in the eighth century of our era."

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# CHAPTER XII

## OCEANS

**Introductory.** — Oceans have geological interest for several reasons: (1) Most sedimentary rocks are of marine origin, and the study of ocean work helps in understanding many sedimentary rocks. (2) Recently upraised sea bottoms now constitute large and important areas the world over. (3) Oceans are the source of most rainfall and (4) in places they regulate temperatures.

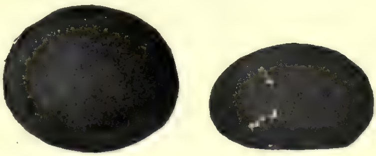

FIG. 243.—Pebbles rounded by ocean waves. About one-sixth natural size.

FIG. 244.—Ocean surf, Canada. (Canadian Geological Survey.)

### Movements

*Waves* and *shore currents* are important geological agents in oceans as well as in lakes; shores are cut and built much the same manner in both bodies of water. *Tides* are important factors in oceans while they are practically negligible in lakes. Tides rise and fall twice a day (twenty-four hours) and have two important geological effects on shore features. In rising and falling, tides widen the zone of wave work;

for example, if the range between high and low tide is 5 feet, the waves can work 5 feet higher than they could without the assistance of the tides. Then the tides moving through narrow channels and bays generate strong tidal currents that are locally important. Ocean wave erosion is more effective than the wave work of lakes because the waves in oceans are higher and stronger and, furthermore, wave work has been in operation longer in the ocean than in lakes, especially extinct lakes. A notable example of wave erosion is the rapid destruction of the island of Heligoland in the North Sea, which has been almost entirely eroded since historical times. The work of waves and currents has been discussed under the topic of lakes because the resulting shore forms in lakes are more important from an agricultural point of view, but it is worth while to consider some ocean shore forms because of their wide extent and because of their potential agricultural importance.

## Shore Features

**Barrier beaches and lagoons** are common along low shelving coasts and they extend with some interruptions along our Atlantic coast from New York to Mexico. The action of lake waves and currents in producing these features has been discussed on page 242. The processes involved when ocean waves are concerned are practically identical and need not be further discussed. The beaches are of little agricultural interest, being for the most part almost pure sand. Atlantic City, N. J., the bathing resort, and Galveston, Texas, are built on barrier beaches, Fig. 245. Between the mainland and the barrier beach is a body of water, either salt or brackish, called a *lagoon* or more commonly, a *sound*.

Fig. 245.—Barrier beaches on the Texas coast.

**Filling of a lagoon** is much the same process as in swamps, except that there are often strong tidal currents in the lagoons. The lagoon, where shallow, supports a growth of rooted plants; grasses and reeds soon form a dense mat which holds sediments brought in by tidal currents or washed in from the mainland. As soon as the water is shallowed so that land is exposed at low tide, the "salt grass" begins to grow and is sometimes cut for hay. Meanwhile sediment is blown into the lagoon from the sandy barrier beach, washed in from the land and carried in by tidal currents through openings in the barrier beach. Mussels and other marine animals may also contribute to the accumulating materials. Thus as a result of lagoon filling there is often a belt of low-lying level land which frequently contains partially decayed plant roots and is sometimes underlain by peat. The soil texture is usually somewhat heavy, although the soil near the barrier beach is often sandy because of the sand that is blown or washed in. The soils near the mainland are also lighter in texture and are somewhat higher, all because of the inwash from the mainland. These marshes are sometimes drained and in cultivation, but reclamation of ocean marshes in North America has hardly begun, although large areas have been brought under cultivation in Europe. These marshes in North America are a valuable reserve of arable land when economic conditions favor their reclamation. Extensive diking is necessary, ditching is required and the soils must often be exposed for a considerable time for the sea salt to be washed out. Salt marsh and fresh-water swamps often meet in estuaries, the marshes extending as far inland as the tides penetrate.


FIG. 246.—Barrier beaches and partly filled lagoons on Long Island, N. Y. (U. S. Bureau of Soils.)

FIG. 247.—Reclaimed tidal flats, Cal. (U. S. Bureau of Soils.)

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**Sea Islands.**—An interesting and important feature off the shore of North Carolina and Georgia is the "Sea Islands" which are well known for their production of sea-island cotton, Fig. 248. The islands are separated by narrow tidal streams and marshes and are apparently the joint result of waves, currents and of scour by the tides, all of which agents have worked over the sediments brought by the rivers. The sea islands are practically duplicated in many shore regions along the Atlantic coast. The arable portions are largely of sandy materials and each island is surrounded by a belt of muck.

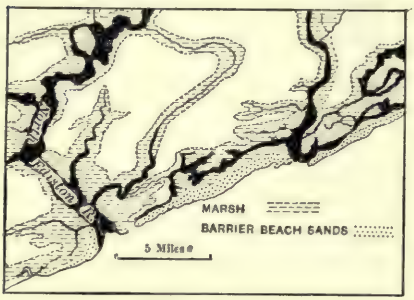


Fig. 248.—"Sea islands," S. C.

### Depressed and Elevated Coasts

**Introductory.**—To ordinary observation, coasts appear stationary, but geological observations show that most of our coasts have been either elevated or depressed within comparatively recent geological time. These movements, however, are so slow that only in exceptional cases of very rapid movement can they be detected as occurring within historical time. Moreover, the coastal movements are seldom simple, a general elevation, for example, often being interrupted at various times by sinking. It must also be remembered that, when one speaks of a rising or sinking coast, the movement may affect large areas both above and below the water, but the movements are more easily recognized at the coast.

**Depressed Coasts.**—When the land adjoining a coast sinks or the ocean rises, the former coast will be submerged. Hills and mountains will be changed to islands. The ocean waters will extend far up the valleys as salt or brackish water embayments and the former valleys may often be traced by soundings for considerable distances beneath the ocean. Such valleys are appropriately termed " drowned valleys." Most of the best harbors of the world are due to the drowning of valleys, examples of which are those of New York, Philadelphia, Baltimore, Liverpool and London. The Hudson River, for example, formerly entered the Atlantic over 100 miles southeast of its present mouth. A considerable depression completely submerged the lower part of the valley and drowned the present valley so that tidal effects extend nearly to Albany, more than 100 miles from New York, and the former deep, canyon-like valley has been filled with thick sediments. The submerged Hudson Valley is shown in Fig. 249.

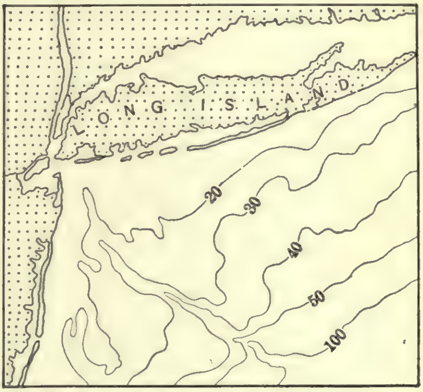


FIG. 249.—The submerged (drowned) lower Hudson Valley. The figures show depths in fathoms. (U. S. Coast and Geodetic Survey.)

It is, therefore, evident that a strongly irregular coast, deeply notched by estuaries, is an indication of submergence; a possible exception is a fiord coast (page 221), where valleys have been deepened by glaciers, but even many of these coasts are known to have been sunken. The Atlantic coast of the United States is in general a sunken coast while much of the Pacific coast is a risen coast; the contrast between the deeply indented Atlantic coast and the relatively smooth Pacific coast is at once evident from a glance at a map. Evidently the sinking of coasts submerges lands that might be arable but, on the other hand, the process furnishes harbors and facilities for commerce and the waters of the estuaries temper the climate of adjoining regions.

**Elevated Coasts.**—From an agricultural point of view the rising of coasts is extremely important since such a movement adds to the land area of a continent. The uplifted sea bottom is usually smooth because

(1) it has been overspread with sediments which tend to make a smooth surface and (2) it has been but little eroded. Consequently the meeting of land and sea on the smooth surface of the uplifted sea bottom is relatively smooth and risen coasts are usually but little indented. Exceptionally, a rather irregular sea bottom may be uplifted and produce an irregular shore line but such are infrequent. Uplift of coasts is also indicated by cliffs, caves, beaches and other shore features now found in many places above the present water level, the distances above

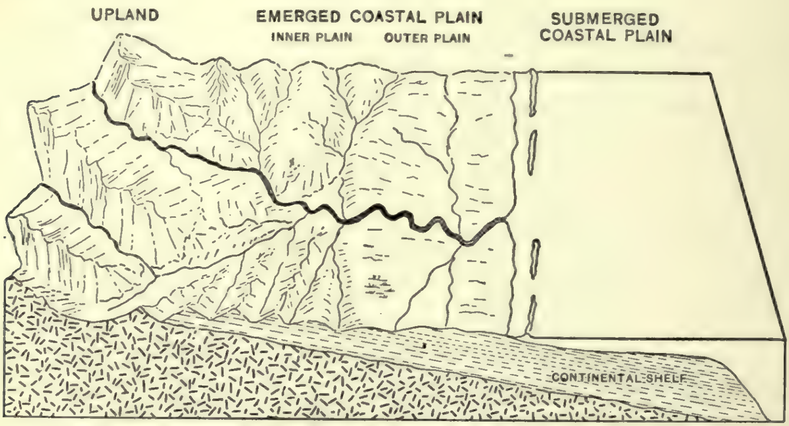


FIG. 250.—The submerged coastal plain and the inner and outer parts of the emerged coastal plain

water level varying from a few feet, showing a slight uplift, to shore features scores and hundreds of feet above the present sea level.

## Coastal Plains

Coastal plains, as the term implies, are plains along the coast, plains varying in width from a few miles to those scores of miles in width. Some narrow coastal plains are due to a slight sinking which has submerged a wider coastal plain, others are due to infilling of sediment from the mainland, but the great coastal plains of the world are due to extensive uplifting which exposes large areas that were formerly sea bottoms.

## The Coastal Plain of North America

This is so extensive and important that it merits a somewhat thorough consideration. It may be said to begin at New York and with some interruptions to extend to Yucatan. At first a narrow strip in New Jersey, the Coastal Plain widens to the southward and attains a width of over 150 miles in Alabama from whence it again narrows through Texas, the whole resembling a vast crescent, interrupted by the Mississippi and other lowlands, Fig. 252. This is one of the most persistent and important features in North America and it includes millions of acres of arable land.

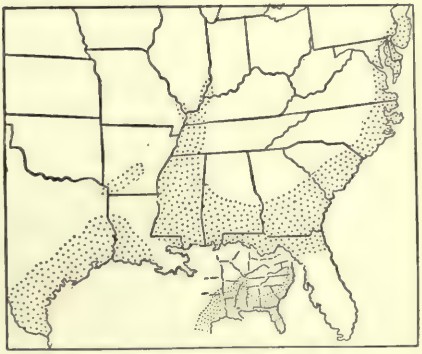

FIG. 252.—Map showing the general distribution of the Lafayette and Columbia formations. (After McGee, slightly modified.) The insert map shows the Coastal Plain.

**Origin.**—The Coastal Plain is essentially an upraised sea bottom much of which has been but a comparatively short time above water and, furthermore, soundings off the Atlantic and Gulf coasts shows that this plain extends beneath the ocean with no notable change or interruption at the present shore, Fig. 250. It will be remembered that the lower Hudson Valley has been drowned and other rivers flowing over the Coastal Plain show submerged lower valleys, and from this and other facts it is clear that much of the former Coastal Plain is now submerged. In other words, the Coastal Plain was formerly above water, at least long enough for rivers to cut deep valleys in its surface, and then much of the plain sank so that the Atlantic and Gulf meets the land along the present indented coast; the Coastal Plain, therefore, consists of two parts, the *emerged* and the *submerged*.

**The materials** of the Coastal Plain are derived from sediments which were washed into the sea from the lands and from the skeletons, shells and other remains of animals which have accumulated on the ocean bottom; in places there are deposits of lignite due mostly to the partial decay of plants. Typically the sediments are unconsolidated and consist mostly of sands and clays although locally there are sandstones, limestones and shales. Most of these materials are stratified and in general the strata dip gently seaward toward the Atlantic and the Gulf of Mexico. The low dip brings to the surface the edges of the strata as heretofore explained, Fig. 51, so that the various formations come to the surface in belts that are roughly parallel to the coast.

**Boundaries.**—Thus, in passing across the Coastal Plain from the shore inland, one will cross successive belts, each older than its shoreward neighbor. Finally at the edge of the Coastal Plain there are older rocks from which the sediments of which the plain is composed were derived, the sediments being washed down from these rocks into the ocean which then covered the Coastal Plain. From New Jersey to central Alabama these older rocks are mostly crystalline, they rise above the plain and the feature in general is termed the *Piedmont Plateau.* From Alabama to Texas these old rocks are largely sedimentary. As streams cross from the harder older rock to the weaker rocks of the Coastal Plain, there are usually found rapids or falls near the junction of the older and younger rocks and hence this boundary of the Coastal Plain is sometimes called the *Fall Line* although " fall zone " would be a better term. There is seldom a sharp topographic boundary between the rocks of the old land and those of the Coastal Plain except in some parts of Texas where faulting has produced steep slopes between the two divisions, Fig. 62.

FIG. 253.—The Coastal Plain, Va. (U. S. Geological Survey.)

**Erosion of the Coastal Plain.**—This uplifted sea bottom was at first smooth and, indeed, much of the area now has such a gentle slope seaward that it appears flat to the eye and so gentle are the slopes that much of the rainfall sinks into the soil instead of running off. The erosion, however, in all parts has not been equal. The regions next to the older rocks have been longer exposed; they are, in general, higher than the regions nearer the ocean and are, therefore, more hilly. The seaward region, on the other hand, has been exposed to erosion for a comparatively short time, it is lower and, in consequence, the surface is but little eroded and many areas are substantially the same as when they emerged from the waters. Thus, in most parts of the Coastal Plain, there are two distinctive belts although the boundaries are indefinite,—the inner (higher and older) belt, often known locally as "The Hills," and the outer and lower belts, commonly termed "The Flats." These features are illustrated in Fig. 250, which shows the submerged portion known here as the *Continental Shelf* and the emerged portion with its smooth and eroded portions.

As the Coastal Plain is eroded, the more resistant formations will stand out as ridges and the less resistant ones will be more rapidly reduced to lowlands. The ridges of the resistant strata will typically have a gentle slope seaward with the dip of the rocks and a steeper slope to the landward; such a ridge is termed a *cuesta*. Fig. 251 shows a cuesta and a lowland in a coastal plain, the cuesta being formed by a

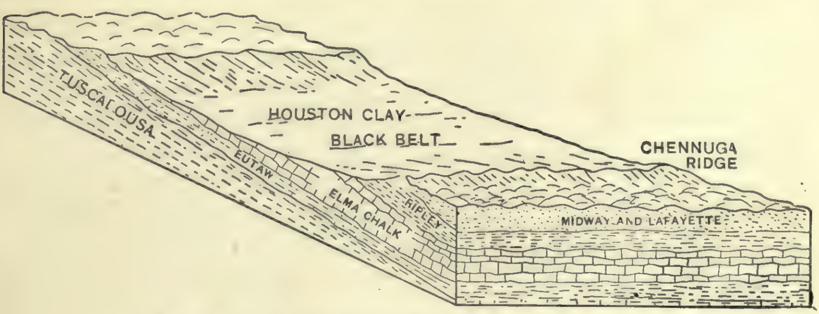


FIG. 251.—A part of the Coastal Plain in Alabama.

somewhat resistant formation and the lowland by the erosion of a weak chalky limestone. The diagram shows Chennuga Ridge, one of the largest cuestas in America. This ridge rises gradually from the lowlands on the south and descends rather abruptly to the Black Belt on the north, so called from its black soils. These features extend more or less parallel to each other across Georgia, Alabama and Mississippi. It often happens that formations making cuestas and lowlands change their character so that these features are seldom continuous for very great distances.

**The Lafayette and Columbia Formations.**—While the formations of the Coastal Plain come to the surface in roughly parallel belts, the residual soils often show very little of this belted arrangement and frequently they are entirely unrelated to the underlying formations. Sandy soils, for example, are often found overlying heavy clays, clays which would yield heavy soils such as clay loams. The explanation of this is due to the fact that there is a thin mantle, typically sandy, which overlies the formations of much of the Coastal Plain. The soils from this formation are often unlike those from an adjacent underlying formation so that, in the Coastal Plain as a whole, the soils do not show the belted arrangement that might be expected from the belted arrangement of the rock outcrops. This relatively thin blanket, typically of sandy and gravelly materials, belongs to the Lafayette and Columbia formations. These formations are among the most important soil formers in North America.

Of these formations, the Lafayette is the older and most extensive, the Columbia always overlying the Lafayette where they are found together. They are typically sandy and in places gravelly, although often there are considerable areas of clays and silts; the similarity of these two formations often makes it very difficult to distinguish them. In color they are reddish or yellowish, as is attested by such local names as "orange sand," "red hills," etc. The thickness varies greatly sometimes in short distances; thicknesses of over a hundred feet have been observed, while in other places the formations may be absent or only a few inches thick, and probably the formations as a whole are under thirty feet in thickness. It must be remembered that while in Fig. 252 the general occurrences are shown, they are not to be found over the entire areas; they are absent over considerable areas and, moreover, as the soils are studied more thoroughly it is becoming apparent that these formations are so thin in many places that they influence many soils but slightly. In composition and structure, both formations, especially the Lafayette, change quickly from place to place and both frequently show irregular stratification; roughly stratified sands and gravels may be found in one place which may change in a few rods to sands or to unstratified sandy clays.

**Origin of the Lafayette and Columbia Formations.**—Three significant facts are clear. The frequent stratification and rounded gravels indicate unquestionably that the formations were laid down by running water; the fossils often to be found in the cherty pebbles are from older formations which are often far to the northward; the reddish colors and the insoluble characters of the gravels, sands, silts and clays point to long-continued weathering of the rocks from which the Lafayette and Columbia were derived. Two views of their deposition have been set forth. According to one view, the formations were deposited in the ocean as the Gulf and Atlantic were retreating toward their present positions. Another view, which at present seems best to explain the facts, is that much of these materials were laid down by streams flowing over the lands, in short that the materials are river deposited (fluvial) rather than marine. The question is still an open one, with the possibility that both processes may have been involved.

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## Marine Deposits

Marine deposits may for convenience be divided into two classes: (1) those carried from land and (2) those derived from the water itself and its life. *The land sediments* are for the most part deposited in relatively shallow water; they vary quickly as the water deepens so that there are *shore* (*littoral*) *deposits* which extend between high and low-tide levels and *shoal water deposits* which extend approximately to depths of 600 feet. The shore deposits naturally are closely influenced by the shore materials, being sandy, for example, where the shores are sandy; in general, these deposits are somewhat coarse. As deeper waters are reached, the influences of the waves, currents and rivers become less and only finer materials are deposited. Furthermore, in these deeper waters calcareous materials from the shells and skeletons of animals are added to the muds and sands derived from the lands. Thus in some formations, long since changed into solid rock, there are fine sandstones and conglomerates grading laterally into shales and these in turn into limestones, the entire formation representing shore deposition, off-shore deposition and finally deeper water deposition.

**Deep Water Deposits.**—The deeper waters at a considerable distance from shore contain but little land material. From about 1,000 to 15,000 feet the ocean floor is mostly covered with a bluish-gray mud with some shell fragments and frequently intermingled with minute shells. These shells, when numerous, have formed beds of chalk. The minute animals inhabiting the shells live near the surface of the water and, as the animals die, the shells shower down on the ocean bottom. In the deep or abysmal waters the ocean bottom is covered with a reddish clay made by the extremely slow accumulation of volcanic fragments, by minute meteorites and by the insoluble materials of shells and skeletons which have been dissolved during their slow sinking. It is interesting in this connection to note that, with a few possible minor exceptions, the deposits in very deep water do not seem to have any counterparts in our stratified rocks. This indicates that, so far as our observations show, these deposits have seldom, if ever, been raised to form continents or, in other words, the continents and present oceans have always or for a very long time maintained their present locations. Chemical precipitates in the ocean are rare, for the water in the open ocean can rarely become saturated with any soluble materials, salt, for example. On the other hand, alterations by which soluble materials are converted to insoluble compounds and are thereby precipitated are not uncommon. A case in point is the greenish mineral, glauconite, which is a compound of iron, potash, silicon and oxygen. This has been found in process of formation in shallow seas and appears to originate through the interaction of decaying animals and the sea-bottom muds. Glauconite has been used to a limited extent as a potash fertilizer.

**Sea life** is an important geological agent. Most of the sea life, both plants and animals, lives in the more shallow waters, but the surface waters of the entire ocean, especially in the warmer portions, teem with marine life. The shells and skeletons sink to the bottom in relatively shallow waters while in deep waters these materials are wholly or partially dissolved during the long sinking.

Corals are simple animals (polyps), some species of which secrete lime carbonate from the water and build it into their bodies. As the animal dies the skeleton remains and, since most corals live in colonies, their innumerable skeletons form large masses, a coral reef, for example, near Australia being 1,000 miles or more in length. These skeletons become solidified by redissolving and depositing and this process is aided by animals which bore through the coral masses. The coral masses are broken into coral sand by some animals which bore into them and especially are they broken up by the waves which pound them into coral sand, which may be strewn over the ocean bottom. Building species of corals live only in warm water (60° F. or more) and in shallow waters of not over 150 feet depth. They flourish best in moving water free from sediment. Coral skeletons have formed enormous masses of limestone rock, some of which shows the fossil forms in great perfection, Fig. 254.

A great variety of other animals such as oysters, clams, etc., and also minute animals have contributed their shells to ocean mud which has often been changed into rock. An indication of the work of animals and plants in abstracting lime and magnesia from the sea water is seen in the fact that, while lime and magnesia constitute over half the solution load of rivers, the ocean waters, on the other hand, contain scarcely a twentieth of these elements, the reason being, of course, that they are used by sea life in skeletons and shells. Kelp, a large sea weed, has agricultural interest because this plant secretes considerable potash, which is now being extracted on a commercial scale.

FIG. 254.—Ancient and extinct coral at the left; modern coral at the right.

It must not be forgotten in this connection that sedimentary rocks of considerable importance have accumulated in other bodies of water than oceans. Many of these rocks were accumulated in extinct lakes and even in rivers. Indeed there are extensive formations, largely of sandstone and conglomerate, which are believed to have been deposited on land. A case in point are the alluvial materials which were washed from the Rocky Mountains and strewn over the plains to the eastward, page 174.

FIG. 255.—Coquina limestone, a mass of cemented shells at the left; coralline limestone in the center; massive limestone at the right.

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## CHAPTER XIII

## MINERAL FERTILIZERS

### PHOSPHATES

**Kinds.**—Phosphates are combinations of phosphoric acid with some base like lime or iron. There are many different varieties of phosphates, but those used for fertilizing purposes are confined to the phosphates of lime, of which apatite is the crystalline form and phosphorite is the non-crystalline, amorphous and usually impure phosphate of commerce.

Apatite $(Ca_5(ClF)(PO_4)_3$ (page 8) is a very common though not extensive mineral of igneous and metamorphic rocks, and in all probability these rocks are the primary source of commercial phosphates. Apatite is very seldom found in sufficient quantity to admit of direct production, but in a few instances it is produced in small quantities as a by-product in some mining operations. Phosphorite is an inclusive term covering the more or less impure and amorphous deposits of lime phosphates.

**Phosphate-bearing Rocks.**—Fig. 256 shows the phosphoric acid content of various rocks. It should be remembered, however, that,

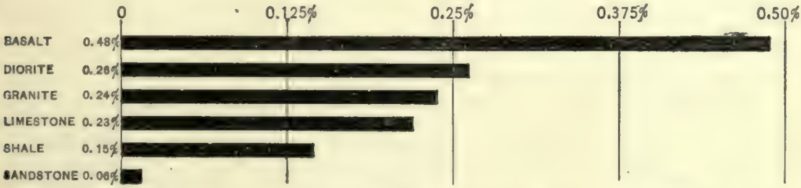


**Fig. 256.—Diagram showing a comparison of phosphoric acid, $P_2O_5$ (black lines) in different rocks. (Data after Stokes and Daly.)**

owing to the relatively small number of analyses, the conclusions are only tentative and may not hold indefinitely. The igneous rocks have a relatively high phosphoric acid content almost entirely in the form of apatite, the lime phosphate. The ferro-magnesian rocks show a high content. The limestones easily lead among the sedimentary rocks and in this connection it will be remembered that phosphatic limestones are the chief source of phosphoric acid for commercial purposes. A fair amount is found in shales, while sandstones show the lowest content.

**General Origin.**—Commercial phosphate deposits may have formed in several different ways, and all of those known in the United States are found in sedimentary rocks. The following types of deposits may be recognized: (1) Bedded deposits of massive phosphate, of continuous or lens-shaped character, and varying purity, which have formed as chemical precipitates on the sea bottom. The Tennessee blue phosphates and the Idaho ones are of this type. (2) Replacement deposits, formed by the leaching of phosphate from guano or higher lying phosphatic formations, and its deposition in lower lying calcareous rocks. The hard rock deposits of Florida are in this class. (3) Residual deposits formed primarily by the leaching of lime carbonate from phosphatic limestones, thus leaving the phosphate of lime behind in a more concentrated form. The brown phosphates of Tennessee are in this group. (4) Mechanically formed or placer deposits due to the sorting over of phosphatic rocks by wave or stream action. The land pebble of Florida is a marine placer.

Fig. 257.—Nodules of lime phosphate, one-sixth natural size. The phosphate was carried in solution and deposited as nodules.

There are many limestone formations in different parts of the world which contain nodules of phosphate of lime, but they are often too low grade to be worked for commercial phosphate. None of value are found in the United States.

Guano is also used as a fertilizing material, but the commercial supply comes chiefly from South America.

**The primary origin** of phosphates is but little understood, but probably, as has been noted, they were originally in the form of apatite; the phosphates have often undergone many changes before assuming their present position; " they may exhibit considerable complexity of origin, involving in some cases several shifts of the phosphatic material " (Ries). The original apatite of the rocks was slowly dissolved in water and carried to the seas from which it was assimilated into the bones, shells and tissues of sea animals. As the animals died their remains settled to the sea bottom where they were subjected to the leaching and concentration which have been described and when conditions were especially favorable, accumulations of phosphorites resulted. In a sense phosphatic limestones are impure limestones, the lime phosphate along with iron oxides, clay and other materials being more or less incidental. Nearly all sedimentary rocks contain some phosphate as is shown by Fig. 256. As a rule phosphatic rocks do not show any special characteristics whereby they may be readily recognized and they are seldom discovered except by chemical tests. There is, therefore, reason to believe that in all probability there are many undiscovered phosphatic rocks in North America.

(5) Finally, streams have eroded phosphatic formations and concentrated the nodules in the stream deposits, a type well shown in Florida.

### Phosphate Producing Regions

The United States is by far the leading producer of rock phosphate and enormous reserves are as yet practically untouched. Rock phosphate is one of our principal exports to Europe. Phosphate is a very important factor in the production of the world's food supply. At present the principal phosphate-producing fields in North America are in Tennessee and Florida.[1]

## The Tennessee Phosphates

These phosphates are found in five ancient formations of Ordovician and Devonian ages (page 294). The phosphatic strata are by no means continuous and a single stratum may vary greatly in thickness and in phosphate content. *Residual phosphate.*—By far the most important commercial products of these deposits is the " brown phosphate " which is mostly derived from Ordovician limestones and is due to leaching. The brown phosphate is the residual material left after the phosphatic limestone has been weathered and leached. This process is illustrated in Fig. 258, where stratum *B* represents a phosphatic limestone. The ground water, entering the rock through joints and other openings, dissolves the soluble materials; the calcite and dolomite are more soluble than the phosphatic materials so that the latter are left as residual material

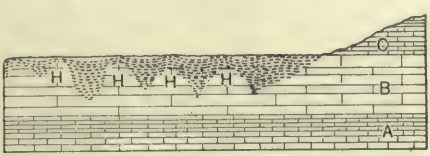


Fig. 258.—Diagram showing the occurrence of brown phosphate in Tennessee. (After Hayes, U. S. Geological Survey.)

[1] The Trenton limestones of Kentucky contain phosphate deposits similar to the Tennessee ones.

along with varying amounts of clay, iron oxides and sand. Solution work is naturally unequal and portions of the rock remain intact, the so-called "horses" (*H*) of the miners (Fig. 258). The strata typically settle unequally, forming the "wavy" structure often seen in the pits and which is shown in the figure. Brown phosphate is taken from open surface pits.

FIG. 259.—Limestone "horses" in brown phosphate, Tenn. (Phalen, U. S. Geological Survey.)

The rocks yielding the Tennessee brown residual phosphates are practically all limestones, from 2 to 8 feet thick, which contain large amounts of fish egg-like (oölitic) grains. These grains are believed by Hayes to be fragments of shells and bones deposited in rather shallow water and rounded by wave and current action.[1] Very probably these grains have been enlarged by coatings of phosphorite which were deposited from the water, Fig. 260.

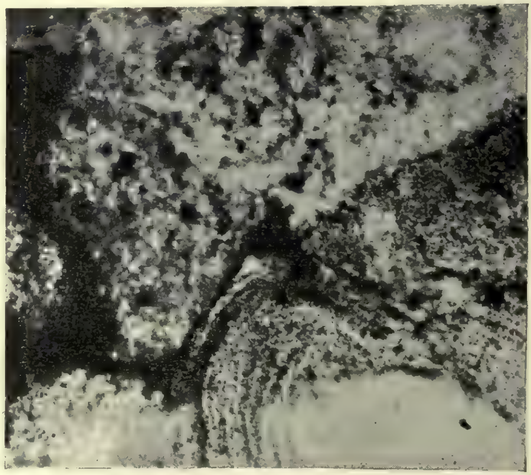

FIG. 260.—Microphotograph of phosphatic rock. Note the deposition bands in the lower right-hand corner. (Tenn. Geological Survey.)

*Bedded Rock Phosphates.* — The less important type of Tennessee phosphorite is found in Devonian rocks which are younger than the Ordovician and which overlie them in places. In contrast to the brown phosphate this

[1] Columbia Folio, Ex. by C. W. Hayes and E. O. Ulrich, U. S. Geological Survey.

rock has not been leached, for it is for the most part not exposed; it is mined underground and is, therefore, more expensive to obtain than the brown phosphate which is mined from open pits. The lower Devonian beds are mostly of black or bluish shale, often termed "blue phosphate"; the thickness varies from a few inches to 4 feet and the percentage of phosphate is also variable, but some beds have the very high percentage of 85 per cent phosphoric acid ($P_2O_5$). In the upper part of the formation are found smooth, dark-colored nodular phosphates often called "phosphate lumps." At present this form is not mined on account of the expense in mining, although some of this bed is very rich.

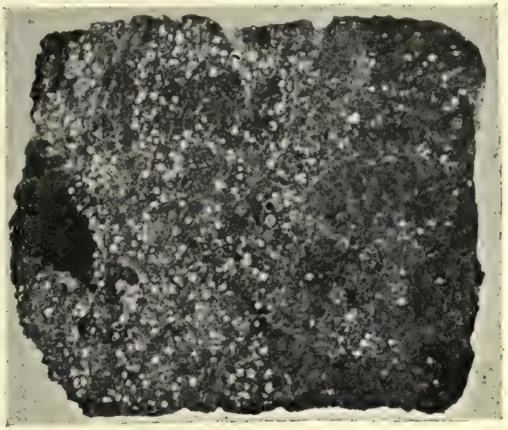

FIG. 261—Oölitic phosphate rock, Montana. The texture is coarser than the average. (U. S. Geological Survey.)

This phosphate probably has about the same origin as the Silurian phosphate except that two special factors are involved. The older and underlying Silurian phosphatic rocks were uplifted, weathered and eroded and their waste was carried into the sea, as shown in Fig. 262, to form Devonian rocks. This Silurian land waste was somewhat sorted by the waves and currents and some of the finer particles were washed away, leaving some phosphatic materials. To this was added the shells and especially the fish remains from the Devonian seas, for this period witnessed a great expansion of fish life and fish bones are highly phosphatic.

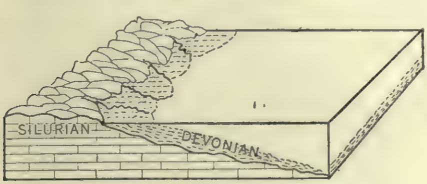


FIG. 262.—Diagram to illustrate the deposition of Silurian phosphatic waste in Devonian seas.

## The Florida Phosphates

These consist of four principal types: Rock phosphate, soft phosphate; land pebble phosphate and river pebble phosphate. **The rock phosphate** consists of fragments of phosphorite varying in size from pebbles to boulders all more or less embedded in sand, clay and soft phosphate. The proportion of rock phosphate to the surrounding materials varies from 50 per cent down, but the commercial mines usually yield from 15 to 25 per cent. There is usually a considerable thickness of overburden, mostly of sand. The thickness of the strata bearing the rock phosphate ranges up to 100 feet, but the usual thickness is much below this. Most of the phosphorite boulders are somewhat spherical and many contain cavities which are often lined with minerals, Fig. 264. The larger boulders are blasted into smaller pieces for the crushers and the pebbles are separated by washing. **The soft phosphate,** when dry, is a powdery mass and, when wet, it forms a sticky mass; it is not mined or recovered at present. There is no sharp distinction between the rock phosphate and the soft phosphate.


FIG. 263.—Map of Florida showing the principal phosphate areas (dotted). (Matson, U. S. Geological Survey.)

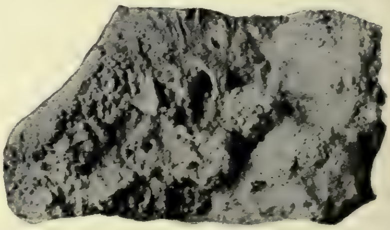

FIG. 264.—Fragment of a boulder of rock phosphate showing part of a cavity lined with crystalline phosphate minerals. (U. S. Geological Survey.)

**The origin** of the rock and soft phosphates is as yet an unsettled question, but it can be safely stated that, like most other phosphorites, these are of secondary origin. The phosphatic materials were originally scattered through the rocks and have been concentrated by the action of water either mechanically or chemically. A mechanical concentration is sometimes found where running water has separated the phosphatic pebbles and deposited them. The chemical work of ground water in these deposits seems to consist largely in the alteration of the original calcium carbonate in the rocks to lime phosphate, a process due to the work of ground water containing phosphoric acid. In most cases this process changes the texture of the original rock and destroys the fossils, but in some instances this does not occur; for instance in Fig. 265 the fossiliferous rock has been thoroughly phosphatized. The most valuable deposits are the boulders and pebbles which appear to be concretions, those spherical aggregates which are found more or less in

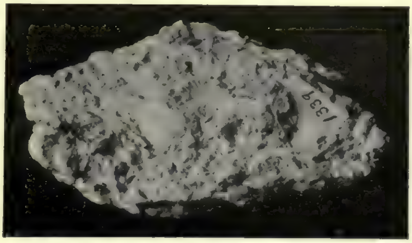

FIG. 265.—Phosphatized limestone, Fla. The original fossiliferous limestone has been replaced by phosphate. (U. S. Geological Survey.)

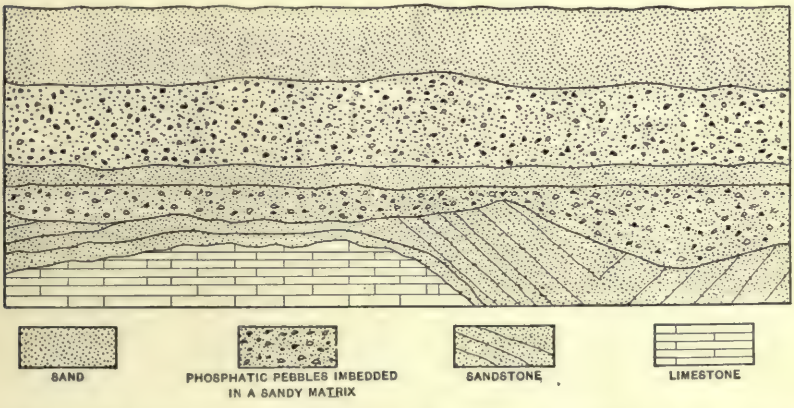


FIG. 266.—An occurrence of phosphate in Florida. (Matson, U. S. Geological Survey.)

all rocks. For some reason not clearly understood, a phosphatic concretion is started and its growth may be continued by the materials brought to it in solution in ground water. In other instances phosphatic boulders were formed by the accumulation of materials in pre-existing cavities. A somewhat typical section of phosphate deposits is seen in Fig. 266, where the mixture of phosphate boulders and pebbles and sand is seen resting on an uneven surface of bed rock.

**Land pebble phosphate** is a mass of phosphate pebbles intermixed with sands and clays. It was formed by waves acting on phosphate-bearing formations, sorting out phosphatic pebbles and depositing and concentrating them. Furthermore, since these pebbles have been deposited, there has been some enrichment by ground water which has dissolved and redeposited phosphatic materials.

**The river pebble phosphate** is a stream deposit. In places this deposit shows rough stratification with intermingled layers of sand, sandy clay and phosphatic pebbles which are usually rounded. These deposits occur in the terraces and flood plains of streams. They, like other stream deposits, are primarily due to the weathering of phosphatic rock, the fragments being subsequently carried and deposited by streams. This type was the first mined, but it is of low grade and little mined at present because the stream separation of the phosphatic pebbles was very imperfect.

**The ultimate sources** of these phosphates are not as yet clearly understood, and with present knowledge but little more can be stated than that the phosphatic materials were derived from one or all of the following sources: (1) Original phosphatic materials in the limestone, (2) phosphatic materials from formerly overlying limestone and (3) phosphoric acid contained in organic matter resting on the surface of the limestone. Such organic matter, either guano or other animal remains, is thought by some to have furnished the phosphoric acid which combined with the limestone materials to form the lime phosphate. This theory is somewhat strengthened by the frequent association of bones and fish teeth with the phosphates. As in so many other geological problems the original rock records have, for the most part, been destroyed and ultimate origins are very difficult to decipher.

## Other Areas

Large areas of phosphate-bearing rocks have been found in Idaho, Wyoming and Utah. Their extent is not yet known and at present they are but little developed because of limited market and lack of transportation facilities. The phosphate formation is from 60 to 100 feet thick and consists mainly of beds of limestones and shales. The main phosphate bed ranges from a few inches to 10 feet in thickness, but the thinner portions are richest. The phosphate content in the workable beds varies from 65 to 80 per cent of lime phosphate, which is a high content. These beds have been folded and faulted so that some are easily accessible. This is probably the largest area of commercial phosphatic rocks yet discovered and it constitutes a phosphate reserve of great future importance. Low-grade phosphate rock has been mined in Arkansas.

## POTASH

*Potash* ($K_2O$) has a wide use as a fertilizer. It is widely dessem-inated in soils, but in many cases the soil potash is in forms not readily available for crops and some soils are decidedly deficient in this food. Potassium is widely distributed through the acid rocks, especially granites and syenites, and it is an important constituent of gneisses and schists. In these rocks it is mainly in the form of orthoclase ($KAlSi_3O_8$), a potash aluminum silicate which has a possible potash content of 19.3 per cent. Orthoclase is probably the principal primary source of nearly all potash, but the mineral is so slowly soluble and so stable that no method has been found to make its potash commercially available. Orthoclase has been ground and applied to soils to a small extent as a potash fertilizer, but the results have not been satisfactory because the mineral is so slowly soluble. Another much less widely distributed potash mineral is leucite ($K_2AlSi_4O_{12}$), a potash aluminum silicate with a possible potash content of 21.5 per cent. Leucite occurs in large amounts in fine-grained lavas of the Leucite Hills of southwestern Wyoming, but so far no practicable method has been devised to make its potash available. Both orthoclase and leucite constitute enormous potash reserves if practicable methods can be devised to make their potash available.

Glauconite, often called "greensand," is a widely distributed potash mineral in the Coastal Plain from New Jersey into Virginia. It occurs in small rounded grains, usually dark green in color, which are often intermixed with sand and bits of shells and is found in beds varying in thickness from a few inches to as much as 30 feet. The composition is somewhat variable, but the mineral is essentially a silicate of iron and potash, that is, it is a compound of iron, potash and silica with a maximum of about 7 per cent of potash. With its nearness to markets and transportation routes, its fair potash content and its easy mining this is a promising potash source, but as yet no process has been found for the cheap potash extraction. It is used locally as a potash fertilizer, but the low potash content will not admit of long-distance transportation. Glauconite is being formed on present sea bottoms but its origin is not well understood. No important supply of potash has yet been found in North America; small amounts in the United States have been extracted from potash-bearing brines and from sea weeds.

**The Stassfurt Region.**—The principal source of potash for the world is from the Stassfurt region in Germany, and the occurrence is so important and so interesting from a geological point of view that it merits a somewhat detailed consideration. The principal potash minerals of this deposit are kainite ($MgSo_4,KCl,3H_2O$), carnallite ($KMgCl_3,6H_2O$) and sylvite ($KCl$); in all, about thirty different minerals have been found in these deposits. It will be seen that these potash minerals are for the most part complex compounds. They are easily soluble in water, a property that makes them especially valuable in fertilizers since the potash compounds are readily available for crops. There are some disadvantages in these fertilizers in that they usually contain considerable salt ($NaCl$); in fact, the potash deposits were discovered when boring for rock salt.

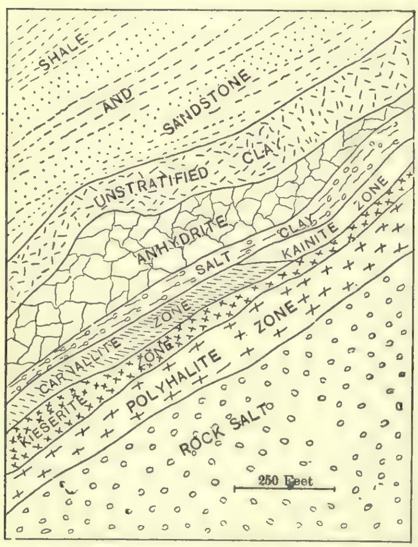


FIG. 267.—Section of the Stassfurt salts beds. (After H. M. Caddell.)

Looking at a section of these deposits in Fig. 267, one notes that they are roughly arranged in layers, although it must be remembered that the layers are not sharply separated from each other and most layers contain other than the principal mineral; for instance, practically all the zones contain varying amounts of salt. These deposits illustrate the general principle of chemical deposition from water, namely that, when water is evaporated, the substances in solution are deposited in reverse order of solubility, least soluble first, most soluble last. One must imagine a more or less enclosed body of water in which the evaporation was in general greater than the inflow. As the waters became more concentrated, the rock salt was first deposited in enormous quantities. Upon this was deposited an impure layer of polyhalite ($2CaSO_4,MgSO_4,K_2SO_4,2H_2O$), a mixture of the sulphates of magnesia and potash together with varying amounts of salt. Then as the waters became more concentrated, the layers of kieserite and carnallite were deposited. The kainite was probably formed by the action of the ground waters after the deposition was completed. Such a more or less definite succession of deposits implies a dry climate, a conclusion which is supported by many other lines of evidence and, moreover, the Permian period to which these deposits belong was characterized the world over by an arid climate.

The stratum of salt clay indicates a break in the deposition when conditions of climate or topography, or perhaps both, combined to bring about a deposition of clay. After this the arid conditions again set in and anhydrite ($CaSO_4$) was deposited in the waters which were becoming concentrated by evaporation and in some places rock salt was deposited on the anhydrite as the waters became more concentrated. Finally, rainfall increased and clays and sands were washed in and now form the clays, shales and sandstones. It is still an unsettled question as to what were the conditions by which the waters contributing these deposits were surrounded. Since it is known that similar geological conditions existed elsewhere during the Permian and other periods, it would seem that other extensive potash deposits may be found, but as yet none of the extent of the Stassfurt deposits have been discovered.

## NITRATES

Nitrates are mined for fertilizers and for many other purposes. The principal commercial nitrate is soda nitre ($NaNO_3$) and the main supply comes from northern Chili, where the nitre occurs in beds up to 6 feet in thickness. The crude material, known locally as *caliche*, is always impure, the commercial beds running from 25 to 50 per cent of nitre. The origin of the nitrates is an unsettled question. The dry climate in which these deposits occur is an important factor in their preservation since the nitre is readily soluble and much would be dissolved and carried away in a humid climate.

## GYPSUM AND LIMESTONE

Gypsum ($CaSO_4,H_2O$), often known as " land plaster," is applied to a considerable extent to alkali soils in some regions of small rainfall. The gypsum combines with the alkaline compounds making them less harmful to crops. It is also used in the manufacture of plaster of Paris, stucco and some cements and plasters. Land plaster is usually impure gypsum which contains more or less sand and clay.

Gypsum occurs in commercial quantities only in sedimentary rocks, beds of gypsum often alternating with beds of limestone. Most salt deposits are more or less associated with gypsum, but not all gypsum deposits are associated with salt. The extensive beds of gypsum, like those of salt, are thought to be due to precipitation from evaporating sea water. Gypsum begins to precipitate when about one-third of enclosed sea water has been evaporated and the process has usually been interrupted before the salt and other easily soluble minerals have been deposited, hence gypsum is often not associated with salt. It is a widely distributed mineral occurring in many parts of the world and in many formations from among the oldest to the youngest.

**Limestones.**—The origin and properties of limestone have been discussed elsewhere. Large amounts of limestone are crushed and ground fine for application to soils, mainly to correct soil acidity. The use of limestone for this purpose is rapidly increasing.

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## CHAPTER XIV

## SOIL REGIONS OF THE UNITED STATES[1]

**Introductory.**—It is not possible to map divisions within which the soils are absolutely distinctive, but for many purposes the soils of the United States may be described under thirteen divisions. Soils are influenced for the most part by three factors; (1) the soil materials;

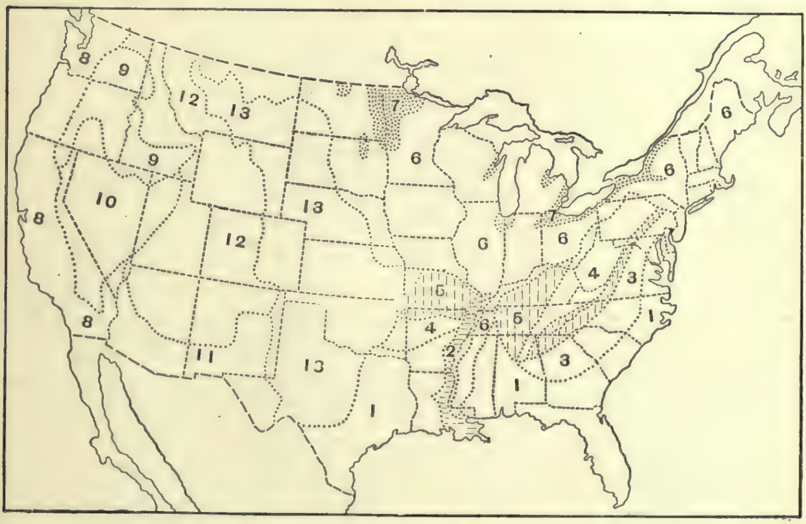


Fig. 268.—Soil map of the United States. (U. S. Bureau of Soils.)

(2) the processes by which the soils have originated; (3) the processes in operation since the soils were formed. It is obvious that all these factors may be in operation in different divisions but their combinations may be so different that the resulting soils may be somewhat distinctive. Furthermore, climate must be recognized also as an important factor, both because of its crop interest and because of its important effects on soils; soils, for example, from the same kinds of rocks in

[1] Abstracted and slightly abbreviated from Bulletin No. 96, U. S. Bureau of Soils.

North Carolina and in Pennsylvania differ because of climatic differences. Each soil division has a somewhat distinctive topography and its soils have resulted from closely associated and somewhat distinctive factors. The map, Fig. 268, shows the principal soil divisions as determined by the U. S. Bureau of Soils.

**The Coastal Plain** (page 265) is one of the most important soil regions of North America. It extends in crescent-like shape from New Jersey through Texas with characteristic soils but with climate varying cool to semi-tropical and from humid to dry. The general structure is shown in Figs. 250 and 251, where it is seen that the underlying formations dip gently towards the Atlantic and Gulf. The rocks are mostly unconsolidated sands and clays, although there are large areas underlain by soft limestones and marly clays and still other areas are underlain by sandstones. These materials have been washed down from the higher lands to the north and west and were deposited in the ocean. The ocean bed was subjected in complicated emergences and submergences, but finally a part of the ocean bed was elevated and now forms the Coastal Plain. Still later much of the Coastal Plain was overspread by a sandy formation, the Lafayette Formation, which yields many of the loams, sandy loams and sands of this division. As a whole the soils are sandy, but varying conditions of drainage give a considerable variety of soils. A belt in Alabama, Mississippi and Texas is underlain by friable limestone which yields the productive soils of the Black Belt (see Fig. 251). As a whole the surface is level to rolling, although markedly hilly regions are not lacking in the older and upper parts; a fairly typical view is shown in Fig. 253. The climate ranges from the cool, humid climate of New Jersey to the warm dry climate of Texas, but the larger areas are located in the South with a warm climate.

**The Piedmont Plateau** lies west and north of the Coastal Plain as will be apparent from the map. As a whole the topography is strongly rolling rather than hilly and, even in areas of high hills, the slopes are often so moderate that tillage is possible from hill base to summit. Between the Coastal Plain and the Piedmont Plateau is the so-called "fall line" or more properly, the fall zone in which streams descend from the Piedmont Plateau by steeper slopes or by falls. The region, as a whole, is in the mature stage of erosion and is well drained by numerous streams. For the most part, the soils are residual and correspond rather closely to the corresponding underlying rocks which are mainly igneous and metamorphic. The soils are in consequence rather heavy, consisting largely of loams, clay loams and clays. The prevailing soil color in the southern parts is reddish and this division is often known as the "Red Land Country." The total area of sandy soils is small.

**The Appalachian Mountain and Plateau Region** is more diversified than either of the two preceding divisions. The main area includes three sub-divisions as follows: The Blue Ridge Region on the east and southeast, the Cumberland-Allegheny Plateau on the west and, between these the Appalachian Valley and Ridge Belt. These are shown in Fig. 269. Besides the main area, there are two subordinate areas, one a large area in the Ouachita and Boston Mountain regions of Arkansas and Oklahoma and the other, a small area in western Kentucky. A small part of this region has been glaciated and its soils will be considered later.

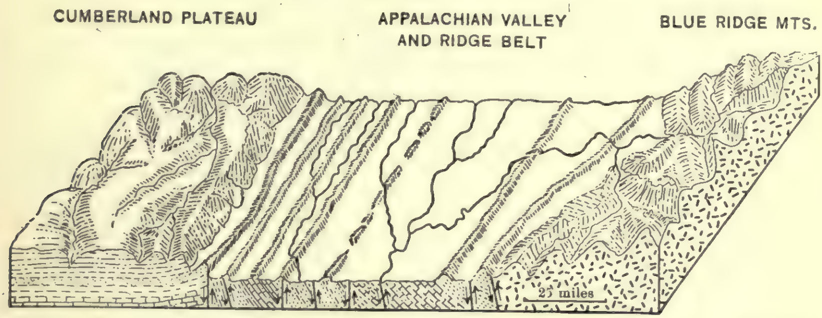


**Fig. 269.—Diagram to illustrate the topography and structure of the Cumberland Plateau, Appalachian Valley and Ridge Belt and the Blue Ridge Mountains.**

*The Blue Ridge Belt* resembles the Piedmont Plateau in its rocks and general geology, the main difference being one of topography and altitude. The Blue Ridge proper is hilly to mountainous, but often there is such a gradation between the two divisions that no definite dividing line can be drawn and, in fact, it is only from Maryland southward that the Blue Ridge becomes a markedly distinct feature. In North Carolina, the highest mountains east of the Mississippi are found in the Blue Ridge. The slopes in general are steep and the soils thin and stony although here and there are rolling plateaus with soils much like those of the Piedmont Plateau. The main agricultural areas are located on the valley soils. Much of the area is in timber and forestry should probably be the main industry for, when the timber is cut, the soils are very easily eroded.

Lying west and generally distinct from the Blue Ridge is the *Appalachian Ridge Belt,* which, as the name implies, is characterized by long, narrow ridges separated by valleys. The rocks are for the most part much vaulted and so intricately folded that the same rock repeatedly appears at the surface in narrow outcrops, Fig. 49. The more resistant rocks like sandstones and some limestones have been less slowly eroded and stand as ridges while the weaker shales and limestones are eroded to valleys, Figs. 56, 57 and 58. Naturally the main arable soils are found in the shale valleys, the soils of which are usually very productive. The ridges are often stony and non-arable and the soils are thin and frequently stony; they are mainly used for pasture, fruit trees or forestry.

*The Cumberland-Allegheny Plateau* is seldom as level as the name might imply; the region was once a plateau, but it has been so maturely eroded that only comparatively small areas of level land remain. Much of the region is markedly hilly, so rough, indeed, that the term mountains is commonly applied to much of the region. The soil-forming rocks are largely shales and sandstones and typically the soils are sandy. The prevalence of steep slopes leads to soil creep, colluvial soils commonly extend around the lower slopes of hills and soil erosion is an important problem. Stony soils and rocky areas are common.

**The Limestone Valleys and Uplands** occur in the western parts of Tennessee and Kentucky and also in the southern half of Missouri and the northern part of Arkansas. The Kentucky-Tennessee region has two main features, the central limestone basin of Tennessee and the similar basin in Kentucky known as the " Bluegrass Country." Both are limestone basins more or less enclosed by higher country known as the " Highland Rim." A section across one of these basins is shown in Fig. 59. The limestone basins have a rolling to hilly topography, they are well drained and, in general, the soils are deep and heavy. The topography of the Highland Rim is much rougher, varying from rolling to much eroded surfaces. The underlying rocks are generally somewhat cherty limestones and the soils are often stony both because of their marked slopes and because of their chert fragments. The best lands are found in valleys and " coves."

The Ozark uplands in Missouri and Arkansas are underlain by a huge dome-shaped uplift formerly a plateau, but now much eroded so that the old fairly level plateau surface is preserved only in patches, while the remaining surfaces are more or less hilly and rugged. The underlying rocks are largely limestones, many of them cherty, and the soils are prevailingly silty loams, loams and clay loams with stony soils from the cherty limestones.

**The glacial and loessial soil regions** constitutes a large and important area which shows considerable soil and topographic diversity. This diversity is due to several factors: (1) The close association of glaciation with loessial soils has been noted (page 234). (2) It will be remembered that there is often a close association of glacial materials with the underlying rocks so that one would expect considerable soil diversity. (3) The glaciated region extends in a general east-west direction and so cuts across several other divisions the northern portions of which have been glaciated. (4) Each division in general preserves its main topographic features, for the glaciers did not greatly modify these features, but the minor features and especially the drainage were often much changed. Probably any soils rather than the topography suffered the greatest changes due to glaciation. It is convenient to consider these glacial and loessial divisions under the following heads:

*The Interior Lowland Area* includes the glaciated areas west of the Allegheny Plateau. This can be separated, both as to soils and to topography, into two divisions, (1) the southern and (2) the northern areas. The southern area is characteristically level or rolling and most of the soils are loessial; these soils show comparatively little variation from place to place. It is an important wheat and corn country. The northern area is predominantly glacial although there is no clear dividing line between the areas. It has a rougher topography, but seldom too rough for cultivation. The soils are much more varied, not only because the glaciers carried and deposited varied materials, but also because of the action of water derived from melting ice.

*The Western Glaciated Area* is much more diverse in topography and it includes practically no loessial soils. The northern part of the Cumberland-Allegheny Plateau, mainly in New York and northern Pennsylvania, has been glaciated. In the main, the surface is hilly and mostly composed of rather steep slopes, but a large percentage of the land is arable. The soils are somewhat thin and show a close relation to the underlying sandstones and shales. Lying to the eastward is a small portion of the Appalachian Ridge Belt. The ridges have generally been swept almost bare of their soils, but the valley soils are productive. In New England glaciation was especially vigorous, much of the preglacial soil was removed and, as a rule, only thin soils were deposited at the glacial retreat. The granites and similar rocks have resisted glacial erosion so that the soils are characteristically stony.

Northern New England is hilly and mountainous and much is too rough for cultivation. The Connecticut Valley, which extends through southern New England, is flocred by fairly productive soils, mostly terrace soils.

**The Great Plains Region** is a large area including a considerable variety of soils, but in the main having a level to undulating surface. On the east, the region lies at elevations of from 1000 to 1200 feet from which it rises very gently to the westward to elevations of from 4000 to 6000 feet. Perhaps the most important soil and agricultural feature is the decrease in rainfall from east to west; in the eastern parts, the rainfall is ordinarily ample while the western portions are semi-arid. It has been noted (page 174) that the western part of this region is more or less covered with materials washed eastward from the Rocky Mountain region. To the eastward of the areas covered by these materials, the soils are mainly residual from sedimentary rocks.

**The Rocky Mountain and Plateau Region** lies in a region of scant rainfall and sharp slopes. The soils are subject to washing and to soil creep. As a whole the region is best adapted to grazing. **The Northwestern Intermountain Region** typically contains two classes of soils: those derived from comparatively recent lava flows, which have been noted on preceding pages (page 36), and the soils in depressions formerly occupied by lakes. All the soils have been greatly modified by wind action, which is especially effective because of the dryness of the climate. Many of these soils are very productive where irrigation water is available since their mineral plant food has not been leached.

**The Great Basin** for the most part is characterized by interior drainage, that is, the escape of water from the region is mainly by evaporation. It is a region of scant precipitation except in the mountains which fringe the basin and the cultivated lands are therefore mainly along the bases of mountains and along the short rivers where irrigation water is readily procured. Numerous isolated mountain ranges and ranges running in a north-south direction rise abruptly from the loose materials of the basin floor. Here, it will be remembered, were formerly vast fresh-water lakes which have disappeared or are represented by shallow water, brackish lakes, Fig. 233. The soils are varied, including residual soils from various rocks, lake soils, wind-blown soils and delta and alluvial fan soils which extend outward from the mountain bases. The limiting agricultural factor is the small amount of water available for irrigation and most of the agricultural lands are suitable only for grazing. These agricultural conditions are mostly duplicated in the

**Arid Southwest Region,** except that the latter is as a whole higher. Alluvial soils are important locally.

**The Pacific Region** roughly consists of two mountainous areas separated by lowlands. Along the Pacific coast the Coast Ranges extend in a general north-south direction. These ranges are pierced by two openings, one at San Francisco which leads to the Valley of California and the other farther north which leads to the Puget Sound Lowland. East of these lowlands are the Sierra Nevada and Cascade Mountains. As a whole, the mountains are non-agricultural regions and the main agricultural activities are confined to the two lowlands.

There is an interrupted valley extending from Puget Sound southward to the Gulf of California, a valley interrupted by the Klamath Mountains of northern California and southern Oregon. Puget Sound at the north and the Gulf of California at the south appear to be drowned portions of this valley. The Valley of California, Fig. 153, which lies south of the Klamath Mountains, is a somewhat unique region enclosed by high mountains with a narrow opening at San Francisco through which the waters of the Sacramento and San Joaquin escape to the Pacific. The valley is about 400 miles long, 50 miles wide and contains something like 20,000 square miles. Typically, the soils and topography are somewhat simple and are arranged in longitudinal belts. The streams descending from the mountains on the east and west are rapid, carrying both fine and coarse debris and have built alluvial fans outward from the mountain bases, thus forming plains which slope gently from the mountains, Fig. 152. Between these sloping plains are the flood plains of the San Joaquin and Sacramento Rivers and in addition there are scattered areas of residual soils. This long valley extends from southern California, with a scant rainfall to the northern part of the State, which has a fairly abundant rainfall.

The northern extension of this valley north of the Klamath Mountains may be considered under two divisions, the Willamette River Valley to the south and the Puget Sound region to the north. The Willamette Valley soils consist of alluvial belts along the streams and residual soils on the lower foothills. Much of the Puget Sound Valley has been glaciated and glacial materials form most of the soils. Both valleys have adequate rainfall.

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## CHAPTER XV

## HISTORICAL GEOLOGY

**Historical geology** deals mainly with (1) the growth and development of continents and (2) the evolution of the earth's life as shown by fossils. Geological history deals with enormous periods of time and, as in human history, many of the records, especially the early records, have been obliterated. It is convenient to separate geological history into more or less clearly marked divisions of which the following are in use:

| Era. | Period. |
|---|---|
| Cenozoic | Quaternary<br>Tertiary |
| Mesozoic | Cretaceous<br>Comanchean<br>Jurassic<br>Triassic |
| Paleozoic | Permian<br>Pennsylvanian<br>Mississippian<br>Devonian<br>Silurian<br>Ordovician<br>Cambrian |
| Pre-Cambrian | Pre-Cambrian |

### THE PRE-CAMBRIAN ERA

These are the earth's oldest rocks. They are practically without fossils or other evidences of life and are predominantly igneous and metamorphic, although there are large areas of sandstones and conglomerates. These rocks are most extensively exposed in eastern Canada, but there are considerable areas in the Adirondacks, much of New England, the Piedmont Plateau and in many parts of the Rocky

Mountains. They underlie all other rocks. Probably the most important soils derived from these rocks are those of the Piedmont Plateau (page 286). The Canadian area is the largest, but climate and severe glaciation have made many of these soils non-agricultural. The copper and iron of the Lake Superior region occur in these rocks.

## THE PALEOZOIC ERA

**Cambrian Period.**—Life even in this early period was well developed for such well-developed animals as the complex trilobite, Fig. 270, somewhat related to our modern crab, is found in these rocks. Indeed, with the exception of the vertebrates (backboned animals), all the great divisions of modern animals are represented in the Cambrian, but usually in simple and primitive forms. Cambrian rocks, for the most part, are buried beneath younger rocks which have been deposited above them. These rocks are exposed around the edges of the pre-Cambrian rocks in New York, Canada and Wisconsin and in the Appalachians, where folding has brought the deep lying rocks to the surface. The rocks of this period change to those of the overlying **Ordovician** period with no abrupt change in fossils, although fish remains are found here. Much of North America was submerged during this period and in consequence the Ordovician rocks are widespread, although this does not mean that they have a wide surface exposure. Most of the Tennessee phosphates occur in these rocks.

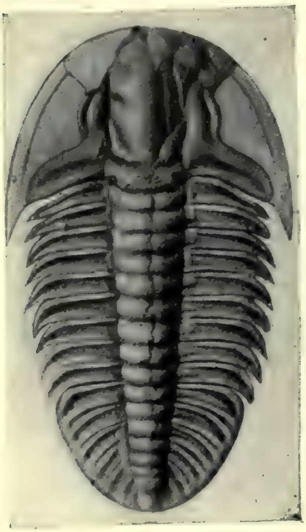

Fig. 270.—A cambrian trilobite, Bathyuriscus rotundatus Rominger. (Walcott, Smithsonian Institution.)

The **Silurian Period** followed without any notable change. Limestones were extensively formed, although shales and sandstones are common. A somewhat arid climate prevailed, at least locally, for extensive salt deposits were accumulated in the central New York region. Another important formation of this period is the Clinton, which extends from New York to Alabama and locally yields much iron ore. Extensive deposits of iron ore are also found in Newfoundland. Silurian and Ordovician rocks in southeastern Canada and northern New York furnished materials to the glaciers so that these formations have had considerable influence in the soils of these regions and even beyond them. Long belts of residual soils from these rocks are found in the Appalachian valleys.

The **Devonian Period** differs but little from the preceding Silurian. The Devonian seas covering portions of North America varied in size. The rocks in New York, Pennsylvania and Kentucky contain important oil and gas formations. This period is especially notable for its number and variety of fishes, all primitive types as compared with modern fishes. These rocks yield soils in southern New York, in Ohio and Indiana and in long, narrow areas in the Appalachian Ridges.

The Mississippian, Pennsylvanian and Permian were formerly included under the name Carboniferous because, during this time, the great coal beds were accumulated. The early **Mississippian** period was a time of widely extended seas in which west of Ohio there were accumulated widespread beds of limestone, some of which now yield large soil areas in the upper Mississippi Basin. Toward the close of this period most of the eastern portions of North America were above the seas.

During most of the **Pennsylvanian** period, the land in eastern North America was low and marshy and the conditions were favorable for coal formation. These favorable conditions were (1) an abundance of vegetation and (2) favorable conditions for accumulation. The vegetation was mostly of tree-like ferns which but little resembled the vegetation of to-day. There are accumulations of peat in the swamps and marshes to-day and these afford an explanation of the formation of coal. When leaves, trunks, twigs, etc., fall to dry ground, they decay, most of their vegetable matter turns to water and carbon dioxide, both of which escape into the air and only the mineral matter or " ash " remains. When, however, the vegetable matter falls into water, the decay is incomplete and the vegetation changes into peat, as has been noted before (page 256). If the peat beds sink at about the same rate as the peat is accumulated, the accumulations may become very thick and very slowly the pressure of overlying materials compresses the peat into lignite and finally into bituminous coal. It is obvious that many feet of peat were required to make one foot of coal and the formation of coal beds required tens of thousands of years. Coal beds are practically always separated by beds of clay, shales, sandstones and even limestones, showing that the coal swamps were subjected to many oscillations.

The **Permian** rocks succeeded the Pennsylvanian without any break, and the main differences were in the life as shown by the fossils. This period the world over was one of large land areas. Three interesting and important events occurred in this period. There was remarkably widespread glaciation even in Africa and India and the areas subjected to glaciation were much more widespread than in the later glacial period, which has been considered at some length. Again, in widely separated areas there are thick beds of salt and gypsum, deposits that indicate an arid climate. Finally, towards the close of the period, the belt now occupied by the Appalachian Ridges was folded and faulted, thus making the beginning of this important topographical region. It should be remembered, however, that the present ridges and valleys of this region are not those which were formed during Permian time, for the rocks have repeatedly been elevated and then worn down; the present rock structure here is the result of the Permian folding. As might be expected, the period is characterized by an expansion of land life, especially plants. The Amphibians which are to-day represented by frogs and salamanders attained large size utterly unlike the present forms. The Pennsylvanian and Permian rocks are largely sandstones and shales; they appear at the surface in northwestern Texas, Oklahoma, Missouri, Illinois and also in wide belts from Pennsylvania to Alabama.

## THE MESOZOIC ERA

The **Mesozoic** is an era in which the life, both plants and animals, increasingly becomes more modern. The era is often called the age of reptiles because of the development and predominance of this form of life. It is divided as follows:

Cretaceous (Upper Cretaceous).
Comanchean (Lower Cretaceous).
Jurassic.
Triassic.

The **Triassic** and **Jurassic** rocks are unimportant so far as covered areas in North America are concerned. There are long, narrow areas, mostly red sandstones and shales, extending from New Jersey into North Carolina and there is an important area in the Connecticut Valley. There are also considerable areas in Utah and Arizona. The distinctive animals of these periods are reptiles which attained great size and diversity. There were also very primitive mammals. A most interesting creature of these periods was the pterosaur, or "flying dragon," as it is sometimes called, which had hollow bones and also wings and was the predecessor of our birds. There was extensive folding of the rocks in the Pacific region.

The **Comanchean Cretaceous** period began with large land areas in North America but, during these periods, the continent sank in places so that there was a vast marine invasion from the Gulf of Mexico to the Arctic, the last great submergence of the continent. It was in this inland sea that the long belt of Cretaceous rocks from Texas nearly to Alaska was deposited. These rocks underlie millions of acres in the Middle West and yield many of the soils of the Great Plains. Gradually this interior sea became shallow and beds of lignite were accumulated over large areas. Finally, toward the end of the Cretaceous, the interior sea withdrew and, with some minor exceptions, the North American continent assumed its present shape.

## THE CENOZOIC ERA

The **Cenozoic** era is divided into a longer early **Tertiary period** and a later shorter **Quaternary period.** The era is sometimes called the age of mammals since these animals became dominant during this time. The life forms more and more approach and finally merge into those of the present.

The **Tertiary** period was characterized by a large land area in North America, an area which was subjected to long erosion—two important and far-reaching events occurred during this period. The formations in the Rocky Mountain region were much folded and these mountains were initiated. Then, especially in the West and Northwest, there was great volcanic activity; the Columbia River lavas, Fig. 28, were in part outpoured during this period. The sediments of much of the Coastal Plain (page 265) were deposited and these sediments now underlie much of this division. Extensive Tertiary deposits were laid down on the land and in lakes, for, it will be remembered, much of the continent was above water during this period. The phosphate deposits of Florida are in part found in Tertiary rocks. It was distinctively a period of mammals of which the early forms were often large and much unlike our present animals, but, as the period progressed, the mammals became more modern in appearance. Of especial interest is the evolution of the horse. In the earlier Tertiary, the horse was a small animal about the size of a fox with four toes on the front feet and three toes on the hind feet. During many generations the legs became longer, the toes were reduced to hoofs, the teeth became better adapted for grazing and the modern horse resulted. Much of the vegetation was similar to modern types.

The **Quaternary** period is the last and includes the present; for example, the materials deposited by a stream at this moment are quaternary in age. This period is of especial interest because many of our soils and much of our drainage and topography have been developed during this period. In the early part of the quaternary, the climate became colder and the great ice sheets of the last glacial period successively advanced from the north, both in North America and Europe. It will be remembered that this glaciation was discussed in a former chapter, and, from a viewpoint of soils, perhaps this glaciation was the most important event in the geological history of North America. Also during this period, the great fresh water lakes of Utah and Nevada were in existence, Fig. 233. The fauna and flora are essentially modern, but the period is important because of the appearance of man.

# APPENDIX

## SOIL MAPS

The following soil maps illustrate different topics. So far as possible, soil maps have been selected which show the topography or for which there are corresponding topographic maps. The (*) indicates that the topography is shown on the soil map. If there are separate topographic maps (sheets) covering the soil maps wholly or partly, the name of the topographic map follows that of the soil map. The soil maps, unless otherwise stated, are issued by the U. S. Bureau of Soils. All topographic sheets, folios, monographs, professional papers, bulletins and water-supply papers are issued by the U. S. Geological Survey unless otherwise stated.

## CHAPTER II

**Dikes and their Soils.**—* San Francisco Bay Region, Cal., 1914, San Francisco Folio; Adam Co., Pa., 1904, Gettysburg and Fairfield sheets (see Fig. 18). **Soils Affected by Vulcanism.**—Reconnoissance Survey of the Sacramento Valley, Cal., 1913, Marysville Folio; Trenton Area, N. J., 1902, Trenton Folio; Fallen Area, Nev., 1909; Austin Area, Tex., 1904, Austin Folio; Reconnoissance Survey of South-central Texas, 1913, Llano-Burnet Folio.

**Residual Soils from Folded Rocks, Mostly Sedimentary.**—Clay Co., Ala., 1915; Eltowah Co., Ala., 1908, Gadsden Folio; Jefferson Co., Ala., 1908, Birmingham Folio; Blount Co., Ala., 1905, Cullman and Springville sheets. Adjacent regions are covered by the Birmingham and Gadsden Folios; Fort Payne Area, Ala., 1903, Fort Payne sheet. Adjacent regions are covered by the Gadsden and Stephenson Folios; Chattoga Co., Ga., 1912, Rome and Ringgold Folios; Walker Co., Ga., 1910, Ringgold Folio; Reconnoissance Survey of Southeastern Pa., 1912; Bedford Co., Pa., 1911. Bedford and Everett sheets; Reconnoissance Survey of South-central Pa., 1910; Center Co., Pa., 1908, Bellfonte sheet (in part); Johnstown Area, Pa., 1907, Johnstown Folio; * Lancaster Co., Pa., 1914; Grainger Co., Tenn., 1906, Maynardsville and Morristown Folios; Greenville Area, Tenn., 1904, Greenville Folio; Pikesvile Area, Tenn., 1903, Pikesville Folio; Frederick Co., Va., 1914; Harrisonburg Area, Va., 1902, Staunton Folio; Preston Co., W. Va., 1912; Jefferson, Berkeley and Morgan Counties, W. Va., 1918, Pawpaw-Hancock Folio.

**Soils Affected by Faulting.**—* Montgomery Co., Pa., 1905, Philadelphia Folio; Austin Area, Tex., 1904, Austin Folio; San Saba Co., Tex., 1917, San Saba sheet, Llano-Burnett Folio. Reconnoissance. Survey of Southwest Texas, 1911. The Uvalde Folio shows the structure of part of the area. Washington Co., Tex., 1913.

## CHAPTER IV

**Residual Soils from Sedimentary Rocks.**—Talledega Co., Ala., 1907; Fayetteville Area, Ark., 1906, Fayetteville Folio; * Montgomery Co., Kansas, 1913, Independence Folio; Madison Co., Ky., 1905, Richmond Folio; Rockcastle Co., Ky., 1910, Loudon Folio; Overton Co., Ky., 1908, Standingstone Folio; Reconnoissance Survey of the Ozark Region of Missouri and Arkansas, 1916; Ripley Co., Mo., 1915; Scotts Bluff Area, Neb., 1913, Scotts Bluff Folio; Muscogee Co., Okla., 1913, Muscogee Folio; Lebanon Area, Pa., 1901, Lebanon and Hummelstown sheets; * Lancaster Co., Pa., 1914; Cambria Co., Pa., 1915, Barnesboro-Patton, Johnstown and Ebensburg Folios; Taylor Co., Tex., 1918 (physiographic map included); Mt. Pleasant Area, W. Va., 1910, Charlestown and Huntington Folios; Clarksburg Area, W. Va., 1910; Kanawha Co., W. Va., 1912, Charlestown Folio; * Preston Co., W. Va., 1912; * Boone Co., W. Va., 1913; * McDowell and Wyoming Counties, W. Va., 1914, Tazewell and Pocahontas Folios; * Jefferson, Berkeley and Morgan Counties, W. Va., 1918, Pawpaw-Hancock and Harper's Ferry Folios.

**Soils from Slates.**—Chambers Co., Ala., 1909, Wedowee and Grelina sheets; Cleburne Co., Ala., 1913; Randolph Co., N. C., 1913; Cabarrus Co., N. C., 1910; Randolph Co., N. C., 1913; Granville Co., N. C., 1910; Fairfield Co., S. C., 1911.

**Soils from Metamorphic Rocks and from Igneous and Sedimentary Rocks.**—Talledega Co., Ala., 1907; Randolph Co., Ala., 1912, Ashland and Wedowee sheets; * San Francisco Bay Region, Cal., 1914, San Francisco Folio; Franklin Co., Ga., 1909, Carnesville sheet; Johnson Co., N. C., 1911; Anson Co., N. C., 1915 (geological map included); Union Co., N. C., 1914; Richland Co., N. C., 1916; Chester Co., Pa., 1905, Phoenixville, Honeybrook, Coatesville and Westchester sheets. The Philadelphia Folio covers adjoining territory, Montgomery Co., Pa., 1905, Philadelphia Folio; * Lancaster Co., Pa., 1914; Lehigh Co., Pa., 1912, Hamburg, Slatington, Allentown sheets; Fairfax and Alexandria Counties, Va., 1915, Washington, D. C. Folio; Louisa Co., Va., 1905; * Jefferson, Berkeley and Morgan Counties, W. Va., 1918, Harpers Ferry Folio.

**Soils from Igneous Rocks.**—* San Francisco Bay Region, Cal., 1914, San Francisco Folio; Honey Lake Area, Cal., 1915; Mecklenburg Co., N. C., 1910, part of Charlotte sheet; York Co., S. C., 1905, Sharon and Kings Mt. sheets; Oconee Co., S. C., 1907.

**Inherited Soils.**—Cape Girardeau Co., Mo., 1910 (see Fig. 85); Tishomingo Area, Okla., 1906, Tishomingo Folio (see Fig. 85).

## CHAPTER V

**Soils Affected by Wind Work.**—Reno Co., Kans., 1911, Hutchinson and Lyons sheets; North Platte Area, Neb., 1907; Franklin Co., Wash., 1914, physiographic map included; (see Water Supply Paper Nos. 118 and 316). **Loessial Soils.**—East Baton Rouge Parish, La., 1905, Baton Rouge sheet; East and West Carroll Parish, La., 1908; Lafayette Parish, La., 1915; Adams Co., Miss., 1910; Wilkinson Co., Miss., 1913; Granada Co., Miss., 1915; Jackson Co., Mo., 1910, Kansas City, Independence and Harrisonville sheets; Franklin Co., Mo., 1913; Cass Co., Neb., 1913; Douglass Co., Neb., 1913, Fremont sheet; Nemaha Co., Neb., 1914; Seward Co., Neb., 1914.

## CHAPTER VI

**Soils Modified by Ground Water.**—* Ocala Area, Fla., 1912; Tattnal Co., Ga., 1914; Easton Area, Md., 1907; Oktibebeha Co., Miss., 1907; Duplin Co., N. C., 1905; Scotland Co., N. C., 1909; Columbus Co., N. C., 1915.

## CHAPTER VII

**Soils Influenced by Head Erosion and Soil Creep.**—Calhoun Co., Ala., 1908, Anniston sheet; Cobb Co., Ga., 1901, Marietta and Cartersville sheets; Brown Co., Kans., 1905, Hiawatha and Atchison sheets; * Montgomery Co., Kans., 1913, Independence Folio (see Fig. 165); Rockcastle Co., Ky., 1910, London Folio; Scotland Co., Mo., 1905, Medina sheet; * Lancaster Co., Pa., 1914; * Cambria Co., Pa., 1915; Jackson Co., Tenn., 1913, Cowee sheet. Adjacent regions covered by the Nahantala Folio; Reconnoissance Survey of the Panhandle of Texas, 1910 (see Fig. 110); Upshur Co., W. Va., 1908, Buckhannon Folio; * Boone Co., W. Va., 1913; * Logan and Miller Counties, W. Va., 1913; * Lewis and Gilmer Counties, W. Va., 1915, Buckhannon Folio. **Bad Lands.**—McKenzie Area, N. D., 1907; Morton Area, N. D., 1907.

## CHAPTER VIII

**Braided Streams.**—Grand Island Area, Neb., 1903; Kearney Area, Neb., 1904. **Flood Plain Soils.**—Miller Co., Ark., 1903; Mississippi Co., Ark., 1914; Jefferson Co., Ark., 1915; * Redding Area, Cal., 1907; St. Clair Co., Ill., 1902; New Orleans Area, La., 1903, New Orleans sheet; Concordia Parish, La., 1910; East and West Carroll Parish, La., 1908; Rapides Parish, La., 1916; Holmes Co., Miss., 1908; Adams Co., Miss., 1910; Coahoma Co., Miss., 1915; O'Fallon Area, Mo., 1904, O'Fallon sheet; Atchison Co., Mo., 1909; Platte Co., Mo., 1912, Kansas City sheet; Grundy Co., Mo., 1914; Sarpy Co., 1905; Meigs Co., Ohio, 1906, Keno and Ravensworth sheets; Oklahoma Co., Okla., 1906; Bryan Co., Okla., 1914.

**Terrace Soils.**—Tazewell Co., Ill., 1902; La Salle Co., Ill., Soil Report No. 5, Illinois Ag. Exp. Station, 1913, La Salle, Ottawa and Marseilles sheets; * Amherst Area, Mass., 1903; * Springfield Area, Mass., 1903; Scotts Bluff Co., Neb., 1913, Scotts Bluff Folio; Douglas Co., Neb., 1913, Fremont sheet; Dodge Co., Neb., 1914; Merrimac Co., N. H., 1906; * Oneida Co., N. Y., 1913; Clinton Co., N. Y., 1914; * Stark Co., Ohio, 1913; Muscogee Co., Okla., 1913, Muscogee Folio; Bastrop Area, Tex., 1907, Bastrop sheet; Huntington Area, W. Va., 1913, Huntington and Charleston Folios; Clarksburg Area, W. Va., 1912; Kanawha Co., W. Va., 1912; * Mt. Pleasant Area, W. Va., 1910; * Point Pleasant Area, W. Va., 1910; Parkersburg Area, W. Va., 1908; * Middlebourne Area, W. Va., 1907; * Wheeling Area, W. Va., 1906; * McDowell and Wyoming Counties, W. Va., 1914; * Jefferson, Berkeley and Morgan Counties, W. Va., 1918.

**Delta Soils.**—Indio and Imperial Areas, Cal., 1903 (Salton Sink); San Jose Area, Cal., 1903; Ventura Area, Cal., 1901; Stockton Area, Cal., 1905; * San Francisco Bay Region, Cal., 1914; Reconnoissance Survey of South Texas, 1909 (Rio Grande delta). **Alluvial Fan Soils.**—San Bernardino Valley, Cal., 1904, Pomona and Cucamonga sheets; Fresno Area, Cal., 1912; San Jose Area, Cal., 1903, San Jose sheet; Bakersville Area, Cal., 1904; * San Fernando Valley Area, Cal., 1915; * Riverside Area, Cal., 1915; * Pasadena Area, Cal., 1915, Bitterroot Valley Area, Mont., 1914; Cache Valley Area, Utah, 1913.

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**Colluvial Soils.**—Marysville Area, Cal., 1909; St. Clair Co., Ill., 1912, Belleville sheet; * Montgomery Co., Kans., 1913; * Cambria Co., Pa., 1915, Barnesboro-Patton, Johnstown and Ebensburg Folios; Albermarle Area, Va., 1902; Bedford Area, Va., 1901.

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**Morainic Soils.**—* Portage Co., Ohio, 1914; Pontiac Area, Mich., 1903; Cass Co., Mich., 1905; Oxford Area, Mich., 1905; * Ramsey Co., Minn., 1914, Minneapolis, St. Paul Folio; Racine Co., Wis., 1906 (see Alden, Professional Paper No. 34). Fond Du Lac Co., Wis., 1911, part of area covered by Fond du Lac sheet; Waukesha Co., Wis., 1910, Milwaukee Folio. **Drumlins.**—* Auburn, N. Y., 1904; * Lyons Area, N. Y., 1912. **Glacial Soils Affected by Underlying Rocks.**—* New London County, Conn., 1912; * Plymouth Co., Mass., 1911; Caribou Area, Me., 1908; * Cumberland Co., Me., 1915 (see Monograph 34); * Oneida Co., N. Y., 1913; Clinton Co., N. Y., 1914; Jefferson Co., N. Y., 1911; Reconnoissance Survey of Northeastern Wisconsin, 1913; Marinette Co., Wis., 1909; Portage Co., Wis., 1905; Wood Co., Wis., 1915 (For Portage and Wood Counties, see Geology of North Central Wisconsin by Samuel Weidman, Bull. 16, Wis. Geological and Natural History Survey, 1907). **Relations between Glacial Soils and the Strikes of Underlying Rocks.**—* Orange Co., N. Y., 1912; * Sussex Co., N. J., 1911; **Different Drifts Mapped by Soils.**—* Dane Co., Wis., 1913; Rice Co., Minn., 1909. **Maps Showing Adjacent Glaciated and Unglaciated Soils.**—Stark Co., Ohio, 1913; Reconnoissance Survey of Ohio, 1912 (geological map included); * Dane Co., Wis., 1913.

**Soils of Outwash Plains.**—Long Island Area, N. Y., 1903 (see M. L. Fuller, Professional Paper No. 82); Jefferson Co., Wis., 1912, Eagle and Whitewater sheets. **Eskers.**—Orono Area, Me., 1909. **Miscellaneous Fluvio-glacial Soils.**—*Cumberland Co., Me., 1914; * Bitterroot Valley Area, Mont., 1914; * Oneida Co., N. Y., 1913. **Miscellaneous Glacial Soils.**—* Cumberland Co., Me., 1915 (see Monograph 34); * Ramsey Co., Minn., 1914, Minneapolis, * St. Paul Folio; Seward Co., Neb., 1914; * Chautauqua Co., N. Y., 1914; * Schoharie Co., N. Y., 1915; * Clinton Co., N. Y., 1914; Ohio Reconnoissance Survey, 1912; * Rhode Island Survey, 1904; Soils of North Central Wisconsin by Samuel Weidman, Bull. No. 11, Wis. Geological and Natural History Survey, 1903; Reconnoissance Survey of Part of Northeastern Wisconsin by Weidman, Hall and Musback, Bull. 23, Wis. Geological and Natural History Survey, 1911; see also the soil reports of the Experiment Stations of Illinois and Iowa.

## CHAPTER XI

**Filled and Partly Filled Lakes.**—Hillsboro Co., Fla., 1916; East and West Carroll Parishes, La., 1909 (see Fig. 132); Concordia Parish, La., 1911; * Plymouth Co., Mass., 1911; Cass Co., Mich., 1906; * Orange Co., N. Y., 1912; * Clinton Co.,

N. Y., 1915; Columbus Co., N. C., 1915; Richland Co., N. D., 1908; * Dane Co., Wis., 1913. **Lake Bottom and Shore Soils.**—Fort Wayne, Ind., 1908; Wells Co., Ind., 1915 (see Monograph 41, plate 11); Crookston Co., Minn., 1906 (see Monograph 25); Pennington Co., Minn., 1914 (see Monograph 25); Westfield Area, N. Y., 1901; Vergennes Area, Vt.-N. Y., 1904; Niagara Co., N. Y., 1906, Niagara Folio; Washington Co., N. Y., 1909; * Jefferson Co., N. Y., 1911; * Monroe Co., N. Y., 1910; * Chautauqua Co., N. Y., 1914; Lake Mattamuskeet Area, N. C., 1909; * Fargo Area, N. D., 1903, Casselton-Fargo Folio; Cleveland Area, Ohio, 1905, Cleveland and Berea sheets; Ohio Reconnoissance Survey, 1912; Erie Co., Pa., 1910; Provo and Goshen Areas, Utah, 1903, Salt Lake sheet; Cache Valley Area, Utah, 1913. **Glacial Deltas.**—Tompkins Co., N. Y., 1905, Watkins Glen Folio.

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**Ocean Shore Lines.**—Indian River, Fla., 1913; Long Island Area, N. Y., 1903; Anne Arundel Co., Md., 1909; Charleston Area, S. C., 1904; Reconnoissance Survey of South West Texas, 1911; Jefferson Co., Tex., 1913. **Tidal Marshes.**—* San Francisco Bay Region, Cal., 1914; * New Castle Co., Del., 1915; Hernando Co., Fla., 1914; Hillsboro Co., Fla., 1916.

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